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Jeremy Grotbo

*Portland State University*

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The “ADaM cube”: Categorizing Portland, Oregon’s  
Urbanization Using GIS and Spatial Statistics

by  
Jeremy Grotbo

A thesis submitted in partial fulfillment of the  
requirements for the degree of

Master of Science  
in  
Geography

Thesis Committee:  
Jiunn-Der Duh, Chair  
David Banis  
Hunter Shobe

Portland State University  
2016

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## Abstract

Transportation availability and land use intensity demonstrate a strong relationship, with intense development concentrated near significant transportation investment. Transportation networks evolved in response to emergent transportation technologies and changing urban land uses. The irregular distribution of transportation systems reinforced patterns of land use development, shaping urban form.

Understanding the relationships between transportation and the intensity of land uses allows urban geographers and city planners to explain the urbanization processes, as well as to identify areas historically susceptible to future development. The goal of this research is to develop a quantitative framework for the analysis of the development of urban form and its relationship to urban transportation systems.

This research focuses on transportation accessibility, building density, and the structural massing as the basic metrics in the categorization of urban form. Portland, Oregon serves as the case study environment, while the research methodology examines the spatial and statistical relationship between these metrics for much of the city's urban area. Applying geographic information systems (GIS) and k-means cluster analysis, urban form metrics are compared within the ADaM (Accessibility, Density, and Massing) cube, a model demonstrating comparative relationships, as well as the geographic distribution and patterns of urban form in Portland, Oregon's neighborhoods.

A finalized urban form catalog describes existing urban environments, but also indicates areas of impending transition, places having the strong potential for reorganization with respect to higher levels of transportation accessibility. The ADaM Cube is a tool for characterizing Portland's existing urban form, and describing the vulnerabilities of urban neighborhoods to the pressure of redevelopment.

Key words: Urban form, urban transportation, urban morphology, GIS, spatial statistics

For the support of my partner and parents;  
To the company of good friends and younger brother.

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## **1: INTRODUCTION**

Early in its history, Portland, Oregon developed much like other settlements of the Pacific Northwest. Nearby resources, including fertile soil, dense timber, and a moderate climate drew settlers and industry to the area. Initially, economics and the introduction of new technologies directed this growth. Yet how this development was shaped, and the forms it took are the result of complex and continual processes. Situated at the hub of a growing trade network, Portland developed as the region's principal port, and as a distinctly urban enclave within a mostly rural region. The city's relationship with transportation and more specifically the navigation of urban spaces is essential to understanding the gradual evolution of the city's built environments, as well as the trajectory of future growth and the redevelopment of existing urban form.

Over its 150 year development, Portland has experienced several dramatic changes in policy and technology. Transportation stands among the most formative of influences (Oregon Historical Society 2002). In the late 1850s, investments in wharf facilities and regional roadways were essential in linking industry with natural resources. Continued development of Portland's harbor and the arrival of transcontinental railways in 1880 established the city as the region's most advantageous port, facilitating expansion outward, as well as Portland's integration into a growing global economy (Price et al. 1987, Abbott 2011). The current urban landscape demonstrates the

importance of transportation, its land uses anchored to the roads and railways of the region's past.

This research develops a quantitative model to describe qualitative relationships, examining how urban environments have and continue to evolve in conjunction with the greater transportation network. Understanding how forms develop reveals how land uses interact with transportation, but also how these factors influence the continued alteration of existing urban spaces. Through spatial and statistical analysis, this research extrapolates the physical characteristics of urban space, and prescribes several metrics used to quantify the city's urban form. The standardization of urban form typologies helps to recognize how places differentiate, but also what factors lead to their growth, decline, and transformation, further indicating change within the city's urban landscape.

### **Research question**

*In what ways do transportation and the intensity of land use interact, and how can this information help to better understand the urbanization of Portland, Oregon?*

This question proposes a broad association between transportation and urbanization. More specifically, this inquiry examines the spatial relationship between urban travel (in term of time and distance) and associated development patterns (in both physical land cover and functional land use). This thesis focuses on the physical characteristics of Portland's neighborhoods, observing how transportation and land

cover interact spatially. Ultimately this research examines where distinct urban forms have developed, and what these typologies indicate about the effect of transportation on land use intensity, both past and present.

### **Research need**

“Geography and history fill up the entire circumference of our perception:

Geography that of space, history that of time.” -Richard Hartshorne, 1939

(Cresswell 2013, p. 85)

Cities represent the cumulative acts of society; they are the representation of our labors and our passions. They house us, link us, are made, destroyed, and rebuilt by us. Cities are the physical manifestation of society’s growth. Their form communicates our command of natural processes and our comprehension of the material world. This relationship is mutual however; our environment similarly shapes us. If one’s identity is the product of experience, our memory is invariably linked to place (Relph 1976). A better understanding of cities provides a greater context to history, an explanation if not evidence for our own progress and growth.

This research helps to reveal what behaviors or events have led to specific developments, helping to explain *why* a space looks or functions in a specific way, and *what* factors led to its current state. As a cohesion of various components, Portland exists both as an assemblage of individuals locations and agents, as well a representation of place as a greater whole (Cresswell 2015). Urban environments are in

near constant transition however, from the addition of each new tenant to the redevelopment of entire districts, *Portland* is continually “becoming.” *Place* is a process, its character the summation of decisions past and those yet to come (Pred 1983). This research catalogs change, noting where and with what relationship transitions occur.

Establishing a general catalog of urban form typologies allows for comparative analysis, or indexing of space with respect to observed characteristics, such as transportation accessibility, density or the massing of structures. For instance, this catalog allows for the distinguishing of urban spaces from one another based on measureable and consistent physical metrics. The catalog also offers the most basic index of urban form, allowing an individual to better understand the spatial characteristics supporting particular built environments. For example, an index of transportation accessibility could help in imagining the potential concentration or size of structures in new development based upon previously observed patterns in other neighborhoods. Alternatively, applying these same indices toward existing neighborhoods could reveal trend outliers, places that demonstrate strong development potential but as of yet lack intense land uses. The latter is invaluable in public outreach and long range planning efforts, helping to reveal the neighborhoods most susceptible to development pressure, and rapidly changing urban environments.

This research provides an explanation of what differentiates urban spaces from one another, and moreover how to qualify these distinctions. To accomplish this, this



research establishes a quantitative process to interpret qualitative space. With reference to contemporary literature and with the use of Geographic Information System (GIS), this research develops and employs metrics to evaluate the physical characteristics of urban environments. Taking advantage of spatial statistics, this research further analyzes the spatial relationship of particular development patterns, illustrating urban form through empirical observation.

### **Context**

This research refers extensively to the field of *urban morphology*, the study of urban form, spatial structure, development patterns, and urban progression. The field analyzes the physical or land cover characteristics of space, as well as land use, or functions of development. Much of urban morphology concentrates on mobility, or patterns of movement or interactions within urban landscapes (Levy 1999). In the greater discipline, the *figure-ground theory* is used to analyze the relationship between structural figures (solids), and open ground (voids) used for movement and exchanges among built environments (Lynch 1960).

Evoking urban morphological principals, this research concentrates on the categorization of the urban form of Portland, Oregon, based upon the spatial and statistical relationship between structures and transportation. The creation of urban form typologies demonstrates this relationship, and quantifies the basic physical characteristics of urban space.

## 2: THEORY

### Overview

This research refers to literature addressing urban evolution in the post-industrial era. This research also draws from Portland and the Pacific Northwest's development, examining how urban form responded directly to technology, policy, and the natural landscape. Literature focusing on urban development consistently suggests transportation as a facilitator and shaper of urban form. This research first examines then develops upon a century's long dialogue between urban theorists.

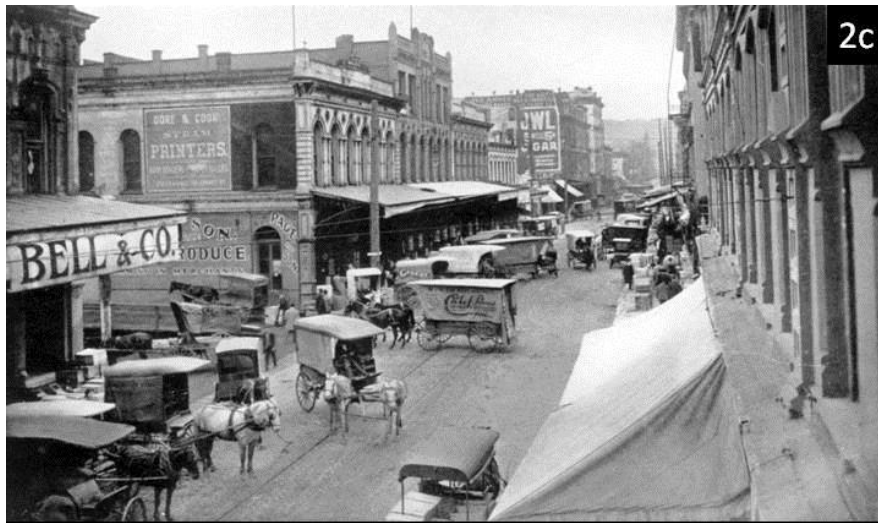
A consistent and central theme, many authors express urbanization as a *process* over time and across distance. Through its progression, urbanization results in the *expansion* of developed forms outward from a core, satisfying economic demand of specific functions in relationship to a centrally accessible area (Mueller 1995, Rodrigue 2016; see figure 2.1). Alternatively, urbanization may involve the *alteration* of previously developed spaces into new forms or functions, facilitating rising demands and responding to changes in adjacent functions (figure 2.2).

With an increase in population or the more intense use of space, demand supports further growth. However constraints, known as friction, limit or slow such development (Rodrigue 2016). Transportation infrastructure eases this impediment with roadway improvement, and the mechanization of travel modes with wheels, electric motors, and petrol engines (Borchert 1967, Hanson and Giuliano 2004).

*Mechanization* also exists as a common theme throughout literature, though its meaning and significance vary greatly between authors. Urban theorists of the early to mid-20<sup>th</sup> century noted mechanization as among the greatest influences on the growth and form of North American cities (Mumford 1961, Mueller 1995, Hanson and Giuliano 2004). Their observations describe rapid suburbanization due to *space/time compression* aided by rapid, long distance travel in streetcars and later the automobiles (Fyfield 2003, Rodrigue 2016). Authors note how cities were intentionally designed with the understanding that urban form reinforces travel patterns (Crane 2000).



Figure 2.1: Urban expansion in Portland, Oregon. Grand Ave. 1919 (2a). Sandy Blvd. 1947 (2b). (City of Portland Archives 2016)



2c

Figure 2.2: Urban alteration in Portland, Oregon. Front St. 1910 (2c). Front St. 1962 (renamed reorganized as Harbor Dr.)(2d). (City of Portland Archives 2016)



2d

For other theorists however, the opposite is as much, if not disconcertingly true (Relph 1976, Camagni et al. 2002). Mechanized travel, and in particular automobile travel, is repeatedly suggested as the most powerful influence in the formation of post-industrial and post-war North American cities. Between geographers, engineers, and critics alike, models, summaries, and literature all point to the automobile as the most influential catalyst in the shaping of urban spaces (Conzen 2001, Rodrigue 2016). While the machines of past centuries supplemented urban growth, the automobile continues

to dominate North American urban development, civic engineering, and retail and commercial interests (Crane 2000, Hanson and Giuliano 2004).

### **Literature review**

Early in the 20th century, those observing rapidly growing American industrial cities attempted to explain the patterns seen within their development. Urban theorists proposed a link between the distances to a city's core, and the types of land uses seen as a result of demand and the function of space. Economists further suggested land uses as the result of micro-economics, echoing earlier claims that a city's form was in large part the consequence of market forces and travel time (Rodrigue 2016). Their models explain travel accessibility as having a direct influence not only toward the costs of travel, but to the value of land, and the intensity and types of land use as a result (Borchert 1967, Knox and McCarthy 2011,).

By the 1950s, theories of *how* cities developed met the criticism of *why* cities followed these patterns. Theorists perceived cities not solely as collections of objects, but as sets of experiences, the consequence of movement and the actions of people (Lynch 1960). A number suggested that cities convey a deeper meaning of culture, communicating environments through their function, use, and interaction (Jacobs 1961). Others saw mid-century development as a result of technological supremacy, specifically the dissociation of man from nature by an increasingly mechanized lifestyle (Mumford 1961). The continued dominance of the automobile in urban space signaled

the departure of cities from human scales and relationships, further reinforced by auto-centric land uses for the sake of motorist conveniences (Mumford 1961, Borchert 1967).

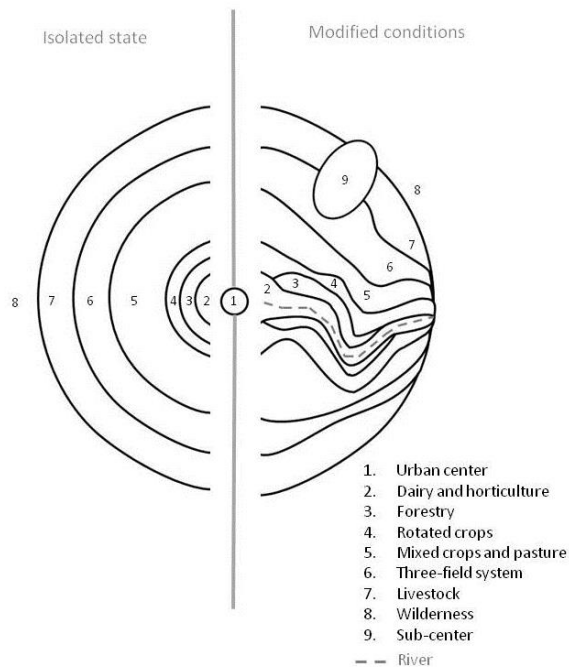
Theorists and economists of the 1970s described urban development as a struggle for political control, as is the case for Marxist geographers. For these individuals, development, landscape alteration, and commuting are all indicative of a primary means of production and dominant economic forces (Harvey 1975). Cities represent trade and exchange, and through their further development, are shaped and arranged by transportation and industrial technology. For Marxists and critical geographers alike, suburbanization was among the recent forms of transportation-based development. Through technology and production, cities relied not on a strength or scale of its citizens, but instead on the limitation of their machines (Relph 1976).

Though late 20<sup>th</sup> century geographers continued to decry this dissociation, they too echoed earlier theorists, claiming transportation among the reasons for such vast, rapid, and sweeping changes found in the growth of North American cities. Contemporary theorists echo the apprehensions casts by their predecessors, but also advocate a reserved optimism. A number suggest cities as the venue for societies continued democratic progression, if not the result of struggle, perhaps through a better understanding of our own “rights” to space (Soja 2000, Gehl 2010).

## Models

Spatial theories appear prominently within urban and transportation research. In over 150 years of both European and North American land use study, authors have explained the characteristics of urban form through the measure, differentiation, and classification of urban spaces (Lynch 1960, Tsai 2005). For most urban models, the *central place theory* serves as a basis framework for continued study and examination. Von Thunen's 19th century *central place model* suggests that travel costs in terms of time and economics influence the land use of an developed location (Rodrigue 2016; see figure 2.4). Each site exhibits an optimal use in relationship to a central urban core. A predecessor to the mid-20th century Alonso and Muth's *bid/rent theory* of economics,

Central place (Von Thunen)



those uses with the highest return value and least demand for space exist nearest to the core, while the opposite is true for those of land uses of lesser market value and greatest need for space (Mueller 1995, Rodrigue 2016; see figure 2.4).

Figure 2.3: Central place theory model (adapted from Rodrigue 2016; see table 2.1)

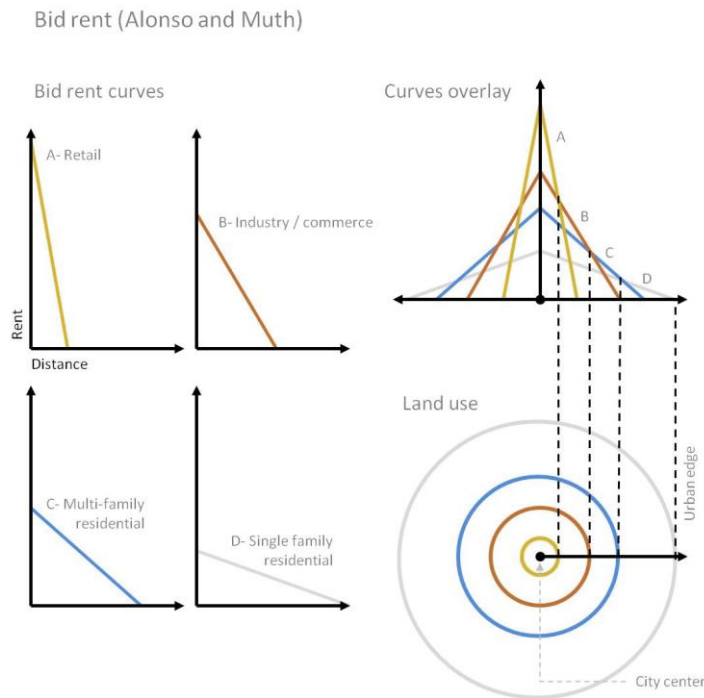


Figure 2.4: Bid/rent model (adapted from Rodrigue 2016).

Both the central place model and Burgess's late-industrial era *concentric model* possess basic assumptions, among them the isolation of an urban core from competing settlements, the lack of differentiated terrain, and

either the absence or even distribution of the transportation network (see figure 2.4, figure 2.5). Hoyt's *sector model* refines the basic concentric land use distribution with an explanation for specific transportation infrastructure. In this model a central urban core continues to exert outward pressure over land use, however roads and railways support linear development patterns, namely by providing increased travel accessibility with reduced costs of travel in their direct vicinity (Borchert 1967, Fyfield 2003; see figure 2.5).

Responding to changes in transportation and the rise of suburbanization in post-war North America, Harris and Ullman's *polycentric* or *nuclei model* suggest specialization of land uses throughout a network of interconnected urban cores. Like the sector model before them, these models propose a strong connection between



transportation and development, in this rise of suburbanization and freeways (Hanson et al. 2004, Rodrigue 2016; see figure 2.5). The sector and nuclei models further demonstrate the gradual evolution of development with respect to changing transportation modes. While railway based transportation systems provided for compact linear development, automobile travel supported more evenly distributed, long distance development loosely connected to regional roadways (Borchert 1967, Hanson and Giuliano 2004).

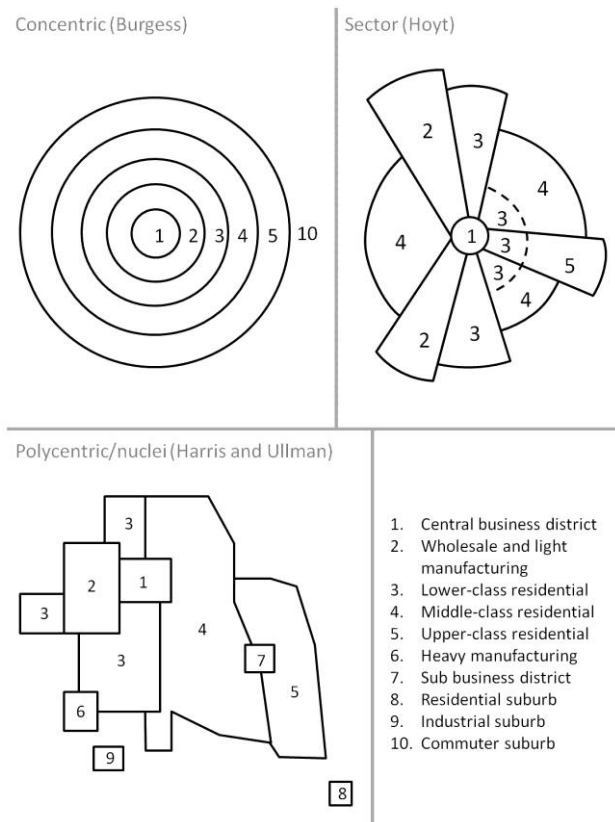


Figure 2.5: Urban models: (adapted from Fyfield 2003; see table 2.1)

In these models *density*, the concentration of structures and a reflection of the intensity of land use, is tied directly to *accessibility*, the ease of travel along a transportation network (Muller 1995, Hanson and Giuliano 2004). The higher the level of demand, the greater the stress place

upon these networks (Rodrigue 2016). The accessibility of an urban environment determines the amount of exchange or capacity of activity at a given location within a transportation system (Ewing 1996, Conzen 2001, Rodrigue 2016). The greater the

accessibility of a transportation system, the greater the potential for exchange, supporting an increase to the *intensity* of land use and demand for further development (Borchert 1967, Mueller 1995).

Table 2.1: Land use models (Borchert 1967, Conzen 2001, Cresswell 2013, Knox et al. 2011, Rodrigue 2016)

Model	Description
Central place (Von Thunen)	One of the earliest and most basic of models, Johan Heinrich Von Thunen developed a model to explain agricultural land use based upon simple economics and demand. In Von Thunen's model land uses nearest to the center require the most intense demand, consumption, and immediate market value (horticulture) while those further out require more space, but less active management (ranching). The model makes broad assumptions: the center is in isolation, no transportation infrastructure is present, and all land is featureless.
Bid rent (Alonso and Muth)	The land rent or bid rent model suggest that patterns of land use are dependent on the demand of an accessible location and the willingness of a specific use to pay a premium for the location. At a central business district, retail uses are assumed to demand highly accessible, trafficked, and visible locations with the greatest cost benefit outcome. Industrial uses still demanding accessibility and proximity to commercial functions downtown will pay for less desirable locations for retail. Residential uses like apartments and condos will come next with a high price per area, followed by single family residential uses. Generally, higher demand and intensity of use results in denser, tall development. The further out from a core, <i>distance decay</i> occurs with greater space and less demand.
Concentric (Burgess)	Developed as a socioeconomic model, Ernest Burgess sought to explain the relationship of wealth classes and distances to centralized urban cores. In this model zones radiate outward from a central business district outward in concentric rings. Each ring represents a specific use, and/or socioeconomic group. Those zones closest to the core represent the densest housing, but also poorest residents. As distance increases from the center, so too does wealth.
Sector (Hoyt)	A refinement on the concentric model, Homer Hoyt developed the sector model to help explain the development of specific land uses found along transportation axis. This model continues to recognize the existence of concentric uses in relationship to an urban center, but considers transportation accessibility, directionality, and corridor land use patterns. This model was built largely in response to the maturity of vast streetcar networks, and the rise of personal automobile use and roadways in then contemporary urban landscapes.
Polycentric/ nuclei (Harris and Ullman)	Recognizing that growth may occur from several nodes and neighboring cities, Chauncey Harris and Edward Ullman developed a polycentric or nuclei model of urban land use. This model reinforces a link between transportation and land use, further suggesting the specialization of industry and commerce in response to transportation accessibility and mode. This model also accounts for the agglomeration of compatible or complementary land use based on mutual benefit. The polycentric/nuclei model is the first to suggest urban fragmentation, or sparse and disconnected suburbanization.

## Research statement

*The goals of this research are to develop a quantitative framework for the understanding of how transportation and the intensity of urban land uses relate, and use the framework to identify areas where urban forms were influenced by transportation and are likely to co-evolve with transportation developments.*

Since its founding, Portland, Oregon's development has relied heavily on investments in transportation infrastructure. The introduction of varying modes of transportation has altered the pace and scale of urbanization, and has continued to support and influence urban growth. While citywide land use development patterns have responded to the introduction of new transportation modes, construction and design has accommodated the demands of specific transportation infrastructure. The physical form of urban environments is in part the result of transportation's effect on space.

Different transportation systems support specific patterns of urbanization. The general characteristics of urban form (land use, and structural density and massing) are of direct consequence to the types and amounts of transportation options available. Since transportation modes have changed over time, the distribution of distinct types of urban development is evident when compared against specific transportation networks and modes, both past and present.

The urbanization of cities demands higher levels of transportation accessibility, necessitating specific transportation infrastructural investments. Developed as a trade center in Pacific Northwestern over 150 years ago, Portland is an ideal location for the study of the relationship between transportation accessibility and the intensity of urban land uses. The most massive, and densely developed urban environments in the city are likely to exist near the most accessible transportation infrastructure. In areas not demonstrating this relationship, factors such as development timing, public policy, or the physical landscape may be responsible for discrepancies and outliers within observed development patterns.

### **Scope of the study**

As explained throughout this thesis, this research focuses on examining spatial distribution and space/time relationships, determining the significance of spatial relationship and patterns of land use for the City of Portland. The data used in this analysis, including building structures, property parcels, census boundaries, roadways, and railways, are represented as geographic polygons, or as tabulated cells. Further explanation and results occur later in this thesis.

### 3: METHODS

#### Introduction

This study relies heavily on spatial statistics in the examination of structure, distribution, and interaction. Techniques used in density clustering, and transportation accessibility analysis are plentiful, their foundational concepts proving helpful toward these evaluations (Dill 2004, Song 2004, Paez et al. 2005). Spatial autocorrelation statistics, which measure how objects are related to or resemble each other with respect to their geographic distance, serve as the primary tool in pattern analysis. Quantitative urban form indices provide a way to transform perceived urban structures and functions into commensurable numbers that can be used for characterizing and comparing spatial patterns.

While pattern comparisons facilitate the investigation of the *what* or *where* of urban form, spatial autocorrelation reveals the *how* and *why*. More specifically, spatial autocorrelation describes the similarity of urban environments based upon the physical, quantifiable characteristics of a location. The total building area within a location for instance is compared to other nearby locations, demonstrating how the building area of these places compares to the distance between them and their geographic relationship. Through GIS, two primary investigations occur: 1) The categorization of Portland, Oregon's neighborhoods based on structural characteristics, and 2) The measure of dependency (spatial autocorrelation) of spatial patterns.

## Design

The research analyzes where and how urban land uses and developments are arranged in Portland, and if these patterns relate to specific infrastructural investments, years of development, or to other land uses. This process relates urban structural forms to the distribution of transportation features within Portland's urban environment. The categorization and classification of the spatial characteristics of space provide a systemic approach to examining the commonalities or distinctions that occur between areas of the city and different periods of time.

GIS uses vector data, (e.g. ArcGIS shapefiles) to represent discrete entities of the built environment, such as building structure and transportation infrastructure. Property parcels and buildings are represented by polygons, roadways by polylines, and roadways intersection by points. Spatial patterns must be quantified in a geographic context, with spatial information organized by local or smaller geographic areas. In this research, census block group boundaries are the spatial unit for pattern analysis because their size consistency and coincidence with roadway boundaries. Census blocks groups are small enough to convey localized scales but not so numerous to overly complicate data analysis results.

Census block groups exist as a unit of convenience for this research. They possess a greater sensitivity of urban texture and meaning comparison than census tracts, official neighborhood boundaries, or an evenly distributed grid. In this analysis, a

census block group is used to describe and approximate a *neighborhood*, a term used interchangeably to describe localized urban scales. The Portland, Oregon city boundary is also referenced for this research. This layer help to define the geographic extent, and isolate areas for analysis (see figure 3.2 and figure 3.3).

Tables A.1 and A.2 in Appendix describes the GIS shapefiles used for this research, their source, as well as the attributes necessary for quantitative analysis and classification. Buildings and property provide basic representation of both formal land cover and functional land use, while buildings supply development years.

Preparation for analysis follows a sequence of basic steps. First a study area is established, focusing on census block groups with a majority of non-recreational or large-scale industrial land uses. Next, data representing building and property metric averages, as well as the total number of roadway intersections are aggregated within each census block group. The aggregated data from each of the census block groups are imported into SPSS and ArcGIS statistics software (k-means and the spatial statistics toolbox), comparing the relationship between this data. Finally, GIS analysis determines the statistical relationship and spatial clustering of census block groups, revealing how they compare to one another as well as transportation infrastructure (see figure A.1).

### **Measurement**

In defining the *density* of urban environments, *clustering* and *distribution* act as descriptions and forms of measurement (Levy 1999, Besussi et.al 2010). Represented as

a scale, clusters range from *agglomeration* to *dispersion*, from those features closely related and found in tight assemblages or modules, to those loosely associated and observed over widely spread distributions. In an urban context, clustering occurs is the result of the positive *spatial correlation* between complementary uses, or in areas of high land use demand (Tsai 2005, Rodrigue 2016). Generally, clustering is associated with denser and more plentiful structures, properties, and overall land use intensity.

Urban transportation systems are generally composed of a hierarchy of roadway types, with a network of primary (arterial) and secondary roadway (Crane 2000; see figure 3.1). The intersections of roadways are used as a measure of the overall *accessibility* of a transportation system (Ewing 1996, Tsai 2005). Roadway hierarchies are strongly associated with the dominant transportation *modes*. Different modes, both in terms of vehicles and infrastructure, required specific roadway treatments, surfaces, dimensions, and orientations. Since the industrial revolution, four major eras have taken place in the Portland metropolitan region, as well as much of the United States (see table 3.1)

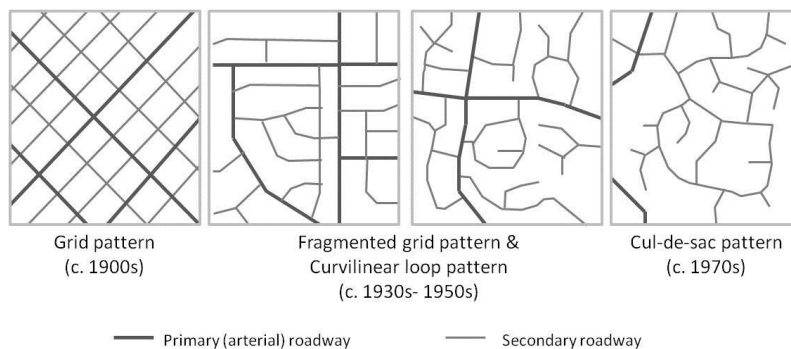


Figure 3.1: Urban roadway patterns (adapted from Ewing 1996, Rodrigue 2016)



Rectilinear grids represent not only the traditional and common roadway layout, grid patterns also maximize the number of roadway *links* for each intersection *node*, providing the greatest potential system accessibility per area (Ewing 1996, Dill 2004). Curvilinear patterns appeared in response to mechanized and longer distance travel, either through the accommodation of gentle railway curves or for higher automobile speeds. However, as the grid represents ideal accessibility, curved links and fewer nodes limit this access, and increase the distance required to traverse space (Cervero and Kockelman 1997).

The metrics used in this study in table 3.2 were formulated in response to those processes revealed through literature review and feature evaluation. Researchers and analysts suggest specific but common metrics and formulas when describing urban spaces, among them frequent reference to both the density of structures and the accessibility of transportation networks as defined by intersection distribution. Massing is a term used more generally by urban planners, engineers, and architectures to approximately the three-dimensional volume of a structure (Bureau of Development Services, The City of Portland 2016.) This metric is used to differentiate tall, bulky structures from low lying, but sprawling buildings. Of the two typologies chosen for this research, era describes the average year of building construction. This typology is used in chronicling the distribution of development across the study area, and is helpful in explaining the processes of urbanization. The other typology, form, comes as a result of

the methodological workflow proposed by this thesis, and refers to the combination of the three metrics used to determine its categorization (see table 3.2).

Table 3.1: Transportation Eras in the United States (Borchert 1967, Mueller 1995, Crane 2000, Ford 2003, Knox and McCarthy 2011)

Era	Years	Description
Walking-horse car (muscle)	Pre-Industrial to late 1880s	The <i>walking-horse car</i> , or muscle era precedes most major modes of mechanized urban travel. Dense, multi-storied cities of mixed land uses and highly accessible road networks define this era. Cities expand outward <i>concentrically</i> along grid-like streets from a central core, but most are limited by how far an individual can walk or ride, both upward in height and outward from a <i>central business district</i> .
Streetcar (electric motor)	1890s to 1920s	With the advent of electric traction, <i>streetcars</i> provided for faster travel over longer distances and challenging terrain. Cities began to grow <i>linearly</i> outward and along streetcar corridors as a result. With an influx of newly developable land, suburban growth accelerated. Combined with the introduction of municipal zoning codes, newer development suggested limited uses, from the creation of suburban business nodes to single family residential neighborhoods. The <i>elevator</i> helped to increase the density and rapid alteration of older neighborhoods, supporting greater building heights and structural mass afforded by steel construction.
Automobile (petroleum engine)	1920s to late 1940s	With mass production, the <i>automobile</i> provided an increasingly popular alternative to public transportation. Automobiles took advantage of existing pedestrian and wagon based roadways, but with wider acceptance began to influence roadway construction, roadside accommodations (parking and auto services), and the adoption of roadway regulations. Initially the automobile supported a continuation of distant, exclusive suburbanization, but its ubiquity replaced nearly all urban transportation by the start of World War II.
Highway (expressway)	1950s to early 1980s	Following the Great Depression and Second World War, specific acts of Congress helped to accelerate even wider scales of suburbanization. Government-backed home mortgages, urban renewal financing, and the creation of the federal interstate <i>highway</i> system encouraged suburban growth and reinforced the dominance of automobile travel. With longer distance travel, suburbs and neighborhoods could but extremely specialized. The grid-like roadways of industrial cities were gradually replaced with limited access, high volume roadways and cul-de-sacs, curves, and terminal streets. Increasingly limited access, hierarchical structure, and single land use districts define the highway era.

Table 3.2: Metrics of analysis

Metric (term)	Description
<b>Numeric</b>	
<b>Accessibility</b> (Ewing 1996, Dill 2004, Song and Knapp 2004)	A comparison of the number of intersection nodes to area. This measures how accessible or interconnected a street network functions, the larger the number, the more connected an area.
<b>Density</b> (Paez and Scott 2005, Tsai 2005, Besussi et al. 2010)	A ratio of building footprint area to the taxlot (or property parcel) area. This measures how much area is dedicated to a structural “solid” versus how much remains as open “void” or general public right of way. The closer the value is to 1, the denser the area.
<b>Massing</b> (Levy 1999, Tsai 2005)	The ratio of total floor area square footage of all structures to property parcel area. This metric helps to describe the type, height, and size of those structures found within an area.
<b>Typologies</b>	
<b>Era</b> (Borchert 1967, Mueller 1995, Hanson and Giuliano 2004)	The year of a parcel is determined by age of the structure occupying the property parcel. A block group’s year is determined by the average year of all those parcels found within it.
<b>Form</b>	Categorization determined by the plotting of census block groups on an x/y/z axis comparing accessibility (x) to density (y) and massing (z). Categories result from the clustering of points within physical characteristics or urban forms.

### Data processing

Figure A.1 in Appendix illustrates the workflow of the research. It begins with the aggregation of metric data pulled from the geometry of road, building, and property ArcGIS shapfiles to census block group boundaries (see figure A.1). The resulting aggregated census block groups represent the research extent and contain all the data necessary for calculating metrics, and for statistical analysis. Data from the statistical analysis are reassigned to each of the census block groups, which in turn are categorized and prepared for final spatial analysis.

Two boundaries were used for the selection of census block groups: the area and boundary for the city of Portland, as well as the officially recognized city neighborhoods (see figure 3.2). Both areas differ in their maximum extent, but in early selection both were taken into consideration.

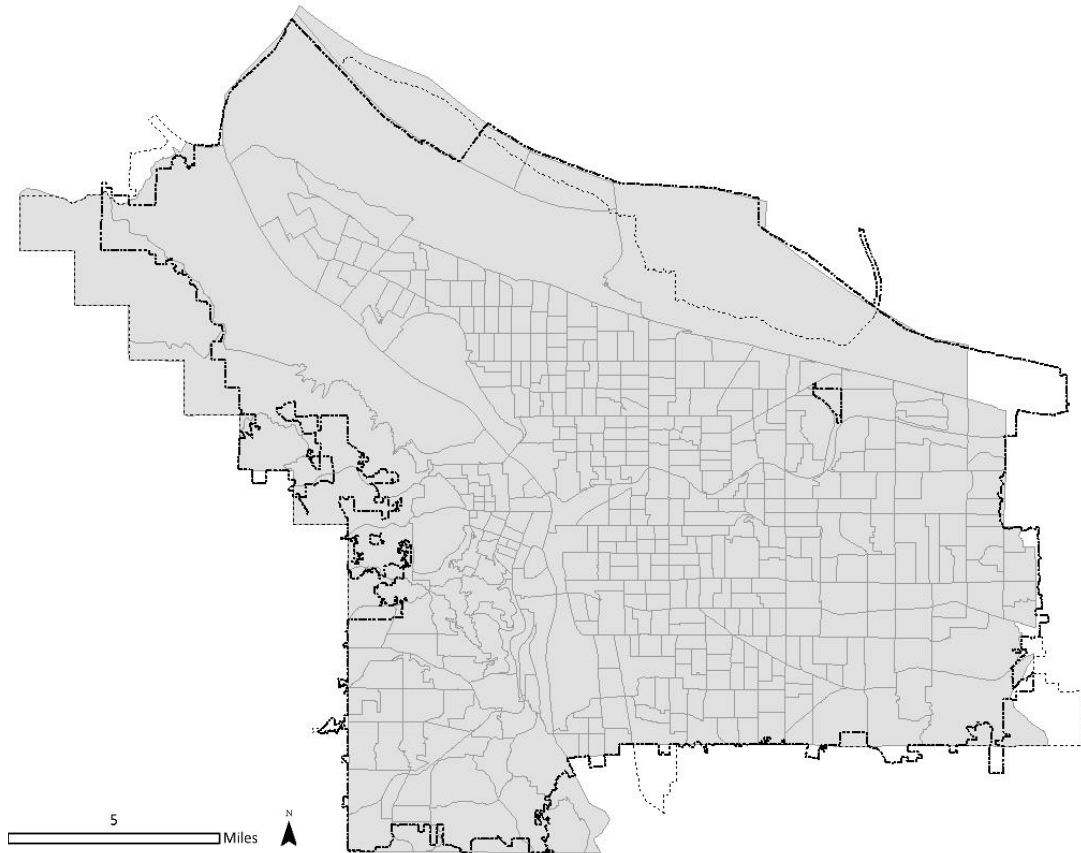


Figure 3.2: Study area extent. Census block groups (shown in grey) within the Portland city boundaries (thick black dotted line) and the outermost city neighborhood boundaries (thin dashed black line).

Having selected local census block groups, building footprints and property parcels are joined with these census block groups by their location. In some cases, the location of a large parcels crossing into one or more census block groups is determined

by the parcel's geographic center. These structural features are used to calculate each census block group's building density, structural massing, and the average year of construction. Density is defined as the ratio of the sum of total building footprint area to the total area of their encompassing parcels, and provides a comparison of building solid to open voids for the entirety of each census block group. Massing on the other hand is defined as the ratio of the sum total floor area for every building to the underlying parcel area. This provides a general description of the types, size, height, and abundance of structures found within a census block group.

Property parcels that have a density value less than 1% (or resulted in a value of less than 0.01) were excluded from the analysis. These parcels are mostly composed of vacant, large, and otherwise undeveloped property, or lack structures and transportation necessary for meaningful analysis. Census block composed of 50 % or more of these types of land uses are removed from further processing, and fall outside the research extent (see table A.1). Conversely, this process analyzes the composition of property parcel land use, not necessarily geographic composition. For instance, those census block groups composed of high percentages of surface water, but with a majority of appropriate land uses are manually retained for data analysis.

The remaining census block groups represent the area within the research extent, and those census block groups used in further data processing (see figure 3.3).

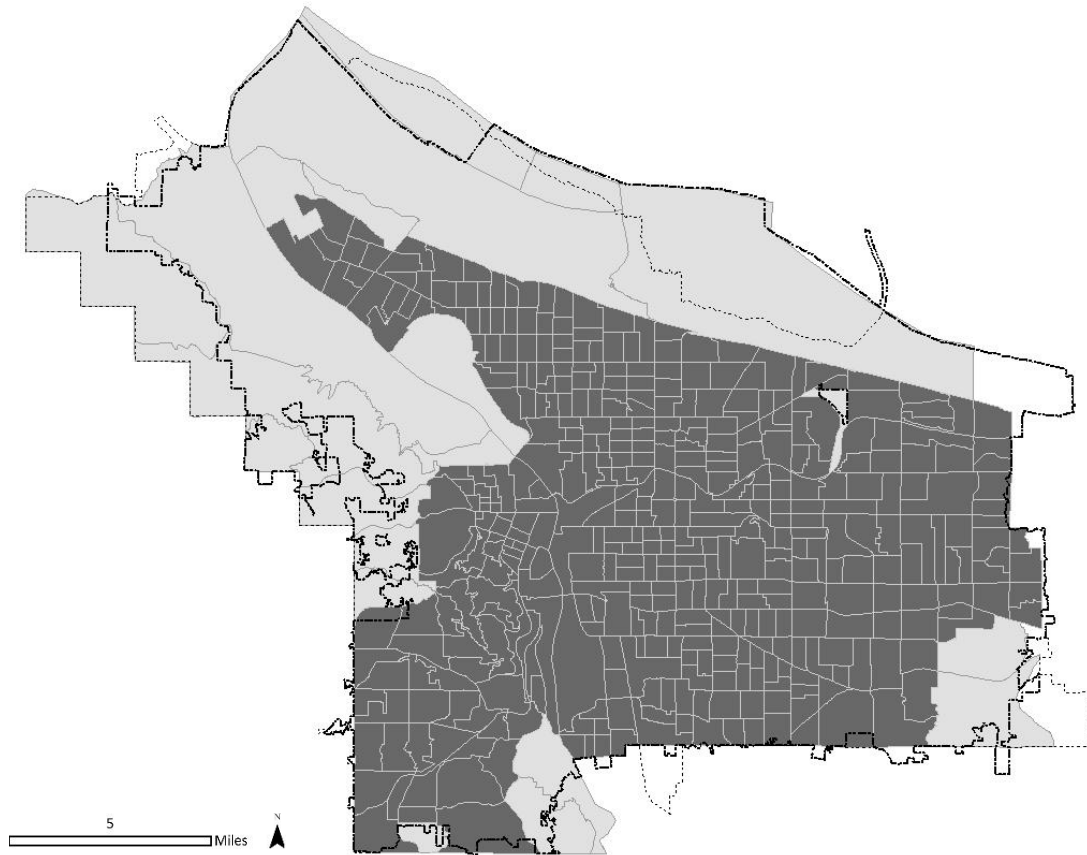


Figure 3.3: Research area extent. Census block groups within Portland area (light grey) as compared to research extent (dark grey).

Accessibility is defined by the number of intersections within a transportation system. Any two streets that intersect form an intersection. To calculate accessibility, street centerlines are fused, or *unsplit*, ensuring that multipart lines are represented as single roadway links. Streets are then *intersected* to produce intersection nodes for the citywide transportation network, resembling a grid composed of streets links and intersection nodes. Intersections are then given x/y coordinates and *dissolved* based upon the x and y fields (see figure A.1). This process is necessary to ensure that

redundant intersections occurring at the same location are reduced to a singular intersection node.

The total number of street intersections is calculated for each census block group. Since census block groups are often bound by streets, a secondary census block group buffer of 100 feet is necessary for each census block group to capture bounding and adjacent intersections. Once the census block group *buffer* contains the intersection total, the buffer's data are joined back to the census block group containing parcel and building information using the FIPS code as the key (see figure A.1).

### **Spatial analysis**

With the property parcel, building, and street and intersection data stored within the census block group shapefile, fields representing the research metrics may be produced. Three numeric comparisons are calculated as follows:

Accessibility = intersection total / block group area (acres<sup>2</sup>)

Density = building area (ft<sup>2</sup>) / property parcel area (ft<sup>2</sup>)

Massing = building square footage total (ft<sup>2</sup>) / property parcel area (ft<sup>2</sup>)

### **Statistical analysis**

The values of each of the census block groups are compared against one another to determine commonalities in urban form. The values for each census block group may be explained as points within an x/y/z three dimension plane, or Grotbo's *ADaM cube*. The placement of these points depends upon the values for **A**ccessibility, **D**ensity, and

**Massing** of each census block group. Accessibility is plotted on the x-axis, density appears on the y-axis, while massing is displayed on the z-axis. Figure 3.4 develops a field visualization of these three numeric classifications and the clustering of points in a three dimensional space.

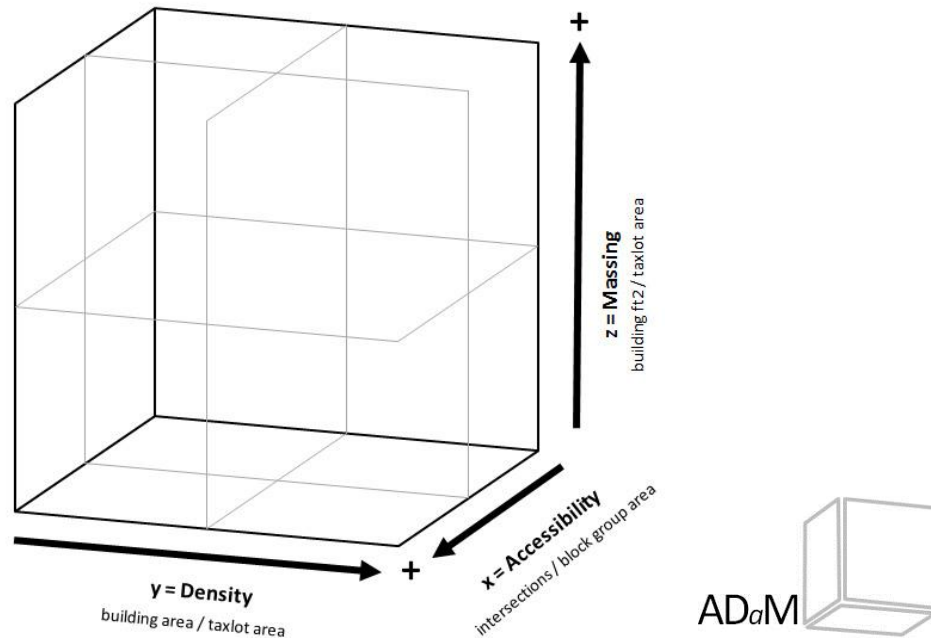


Figure 3.4: The ADaM cube, metric visualization chart (designed and created using Excel 2013, Doka 2013)

Visualizing census block groups as clusters of points demonstrates how each group relates to one another based upon the value of its three numeric classifications. To analyze these relationships more thoroughly, k-means evaluates how these cluster groups relate with one another statistically. K-means analysis determines the similarity of input cases based upon one or more variables and classifies the cases into categories. With values exported from ArcGIS, k-means establishes the *centroid mean*, or geometry



center for clusters of points with common values (SPSS Modeler 2016). K-means is an iterative process, comparing all points found within a plane or planes against the centroid mean of a user specified number of geometric cluster bodies. For this study, the three fields of accessibility, density, and massing serve as x, y, and z value input fields for a visual representation of k-means. Each census block group placement is compared to its proximity to other points sharing the mean values of these three fields. K-means cluster assignments minimize the distance from each point to the centroid of all points within a cluster.

K-means is expressed as:

(SPSS Modeler 2016)

$$\arg \min_{\mathbf{S}} \sum_{i=1}^k \sum_{\mathbf{x} \in S_i} \|\mathbf{x} - \boldsymbol{\mu}_i\|^2$$

number of clusters
number of cases
Distance function

Once categories of urbanization have been analyzed and established, Anselin local Moran's I and local Getis-Ord Gi are applied to the ADaM centroid mean values for each of the census block groups in the study area. This process determines census block groups that have similar ADaM cube clustered in the study area. Local indicators of spatial autocorrelation, or LISA, help to determine locations of similar values, or in the case of this research, places with similar structure and transportation relationships (ArcGIS 2016). While Anselin local Moran's I is useful in comparing individual features, revealing areas of high and low values as well as data outliers, local Getis Ord Gi helps to

reveal clusters of data with similar ADaM cube values, or hot spots within a dataset.

The results of each of these spatial processes are used to create forms of categorization, and explain patterns of spatial development with respect to geographic distributions.

The research model catalogs Portland's urban form. While the former examines the relationships between transportation accessibility, and the intensity of land use, the latter provides specific instances, and degrees of impact within specific neighborhoods. Just as the model reinforces tenants of urban spatial theory, the catalog provides local context, revealing not only how neighborhoods compare with one another, but what attributes are responsible for these distinctions. Additionally, this catalog provides a guide, or instances of the conditions present during development, helping to demonstrate the processes leading to existing urban environments, but also the potential for future development. Further explanation of this process and these results are provided in later sections.

## **4: FINDINGS**

### **Overview**

The findings of the research analysis are described in several parts, beginning first with the results of the ADaM cube, k-means cluster analysis. Subsequent sections focus on each of the primary three metrics and close with a brief assessment and summary of each. An explanation of these individual metrics is essential in explaining how all three influence form categorization. This process is helpful for understanding their role in the shaping of urban form, and how each is represented within Portland, Oregon's urban landscape. Though this research provides a basic workflow for the study and evaluation of urban form, the topic remains complex, and the interpretation of these data require additional explanation in later research sections.

### **Categorization**

Urban form categories resulted from preliminary statistical analysis and k-means cluster analysis performed in SPSS. The GIS data processing workflow produced three primary input values for k-means analysis; accessibility, density, and massing for each of the 418 census blocks groups found within the research area's extent (see figure A.1). Several iterations of k-means were necessary to determine a reasonable number of user specified clusters counts. A range of cluster counts from three to 20 were selected in this process. Of these cluster counts, a count of nine clusters is the most ideal. Any less than nine clusters and nearly half of the extent became over generalized, the detail lost in most of the outer areas of Portland. Greater than nine clusters and each of the city's

downtown census block groups began to class individually, each as a single-instance cluster.

In the final iteration of k-means, seven of downtown Portland, Oregon’s census block groups were weighted and placed into two separate clusters (see table 4.1). These seven census block groups are among the most varied according to local research metrics, but greatly skew categorization of the city as a whole. The remaining 411 census block groups represent seven classes, clusters 3 through 9 (see table 4.1).

Table 4.1: Census block group, cluster designation

Form cluster	1	2	3	4	5	6	7	8	9	total
census block group count	2	5	2	8	13	44	61	141	142	418

Rendering the centroid means of the nine cluster groups through k-means analysis reveals how the research metrics compare between each of these form categories. The populated ADaM cube expresses a strong sequential relationship from a relatively few highly accessible, dense, and massive clusters to the more numerous but less intense areas of the research extent (see figure 4.1). A consistent trend line shows a strong relationship, suggesting that a high value of any of one these metrics would demonstrate higher values for the other two. With few exceptions in later clusters, this trend continues through the sequence, from cluster 1 through 9 (see figure 4.1).

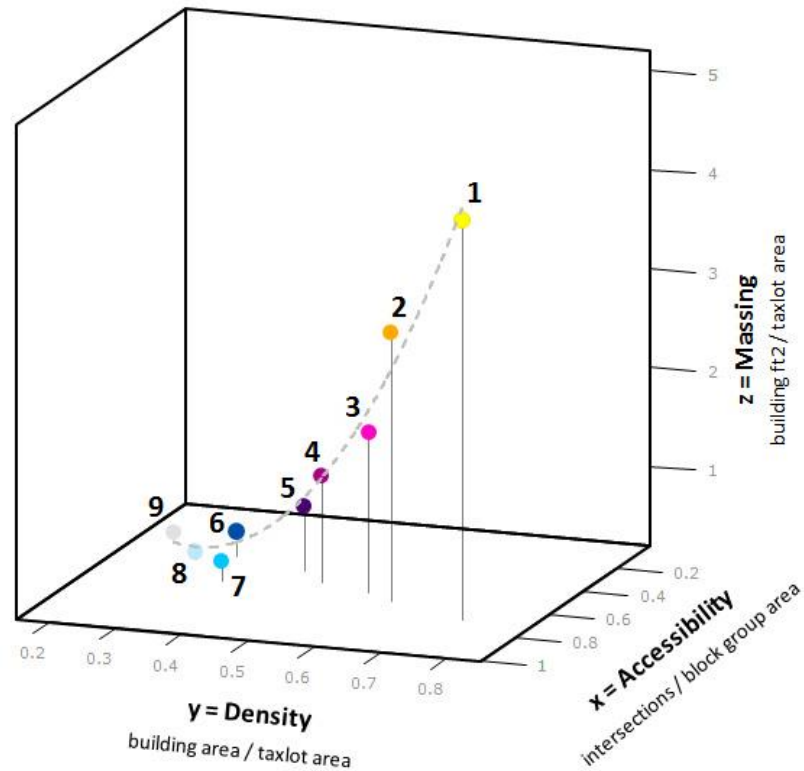


Figure 4.1: Form, ADaM cube result

### Typologies

The results of the clustering analysis define the nine urban form categories observed through metric comparisons. These final clusters are exported back into GIS, and used to reclassify the 418 census block groups, placing each into one of nine form typologies. Geographically, the same trends observed in ADaM cube visualization appear across the city's census block groups. Clusters representing high metric values correspond with relatively few census block groups near the city's urban core. Rapid transition through mid-level clusters gradually disperses into the remaining form categories, spreading outward toward Portland's boundaries (see figure 4.2).

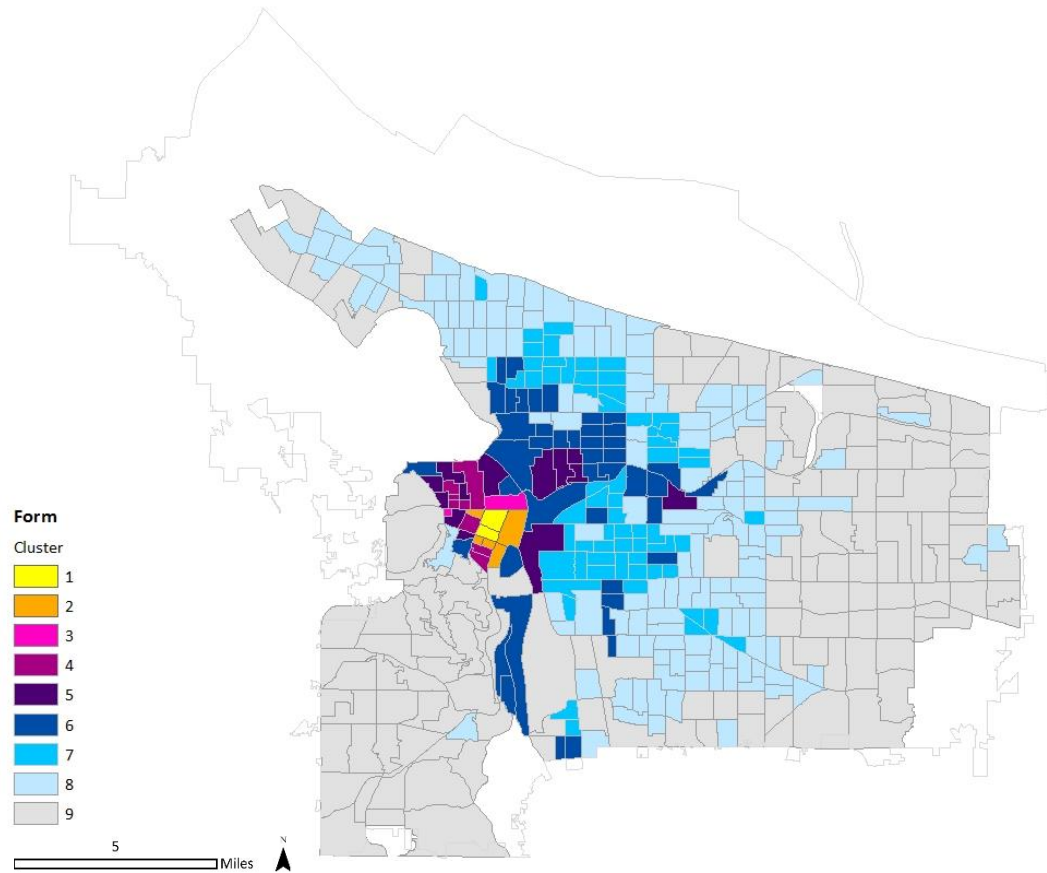


Figure 4.2: Form, geographic distribution

As briefly demonstrated by these final typologies, the research methodology and the results of preliminary data processing support many of the basic tenants of urban spatial theory. Foundational concepts such as centralization and space/time compression are revealed through the distribution of form categories spatially as well as sequentially. Further elaboration of these results requires the examination of each of the three metrics that led to these results. Additional statistical analysis helps to better explain the impact of these findings.

## **Metrics**

Accessibility is determined by the number of intersections occurring within a census block group area. This metric expresses how many intersections on average are found per acre within each of these areas. Accessibility ranges from 0 to 1, with those areas of greatest accessibility having the greatest numeric value.

Generally, higher accessibility suggests a denser or more grid-like roadway network (Ewing 1996, Dill 2004). A high concentration of intersection nodes implies a greater number of routes or links within the overall network, representing a more connected, or evenly distributed transportation system. The most accessible areas of Portland appear near the city's center, though the distribution appears closely related to particular roadways and boulevards extending outward and to the east (see figure 4.3)

Built upon a standardized 200 foot by 200 foot grid, Portland's central business district is among those areas of greatest accessibility. Developers continued this tight grid within early east side neighborhoods, though more distant and newer construction instead relied on longer rectangular blocks, aligning most streets toward downtown Portland and the Willamette River (Portland Bureau of Transportation, PBOT 2016). A coarse overview of citywide accessibility supports this observation, though closer analysis reveals additional influences.

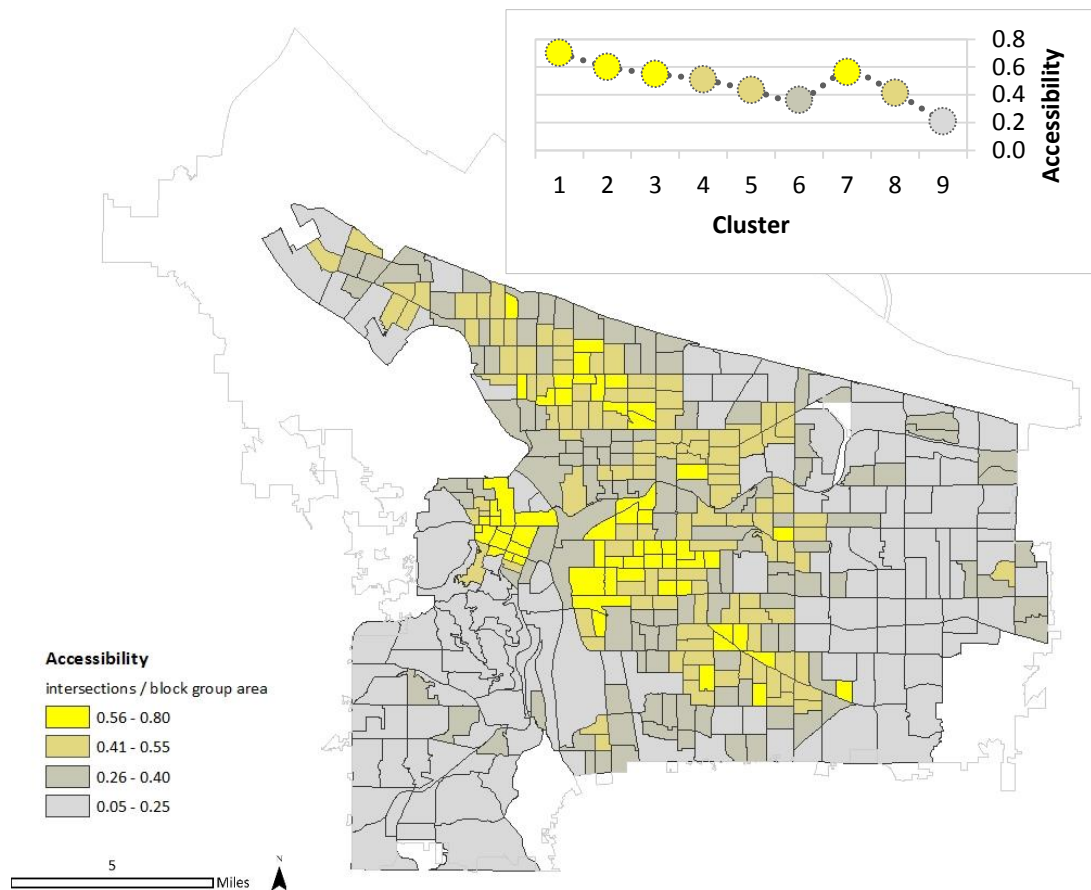


Figure 4.3: Accessibility, distribution by geography and cluster

Though most of the city maintained a semi-regular grid, terrain and hydrography disrupted this pattern, leading to grid realignments along shorelines, and curved roadways following hillside slopes; the Tualatin Hills in the southwest and the north central Alameda Ridge are examples of the latter. Among the most obvious disturbances to the formal grid remains the persistence of early settlement roadways, namely Sandy Boulevard and Foster Road in eastern Portland. The geometry of these diagonal roadways creates more intersections within the grid, providing for shorter more blocks, and corridor-like sectors within the greater transportation network.



Density measures the ratio of space physically occupied by structures to spaces left otherwise open or undeveloped. This metric demonstrates how much of a census block group's property parcel area is composed of building(s). Density ranges from 0 to 1, with those areas of greatest density having the largest numeric values.

Density provides an analysis of the basic urban morphology of Portland. The more dense an area, the more numerous its structures or the greater the size of building found within it (Paze and Scott 2005, Besussi et al 2010). Overall, the most densely occupied areas of the city occur in and near Portland's downtown, with half to over three-quarters of the central business district and inner east side neighborhoods occupied by buildings (see figure 4.4). Generally these are the oldest and most heavily redeveloped sections of the city, having been occupied and re-organized over the course of 150 years of urban development (Oregon Historical Society 2002).

From the central city outward, density slowly decreases (see figure 4.4). Like other metrics, terrain and hydrography disrupt this trend. Conversely, roadway infrastructure supports growth in its direct vicinity, drawing density narrowly outward among more challenging terrain or otherwise undesirable or more difficult to develop locations. Terrain aside, density generally radiates outward from the city center, and is most sparse toward the edges of the study area.

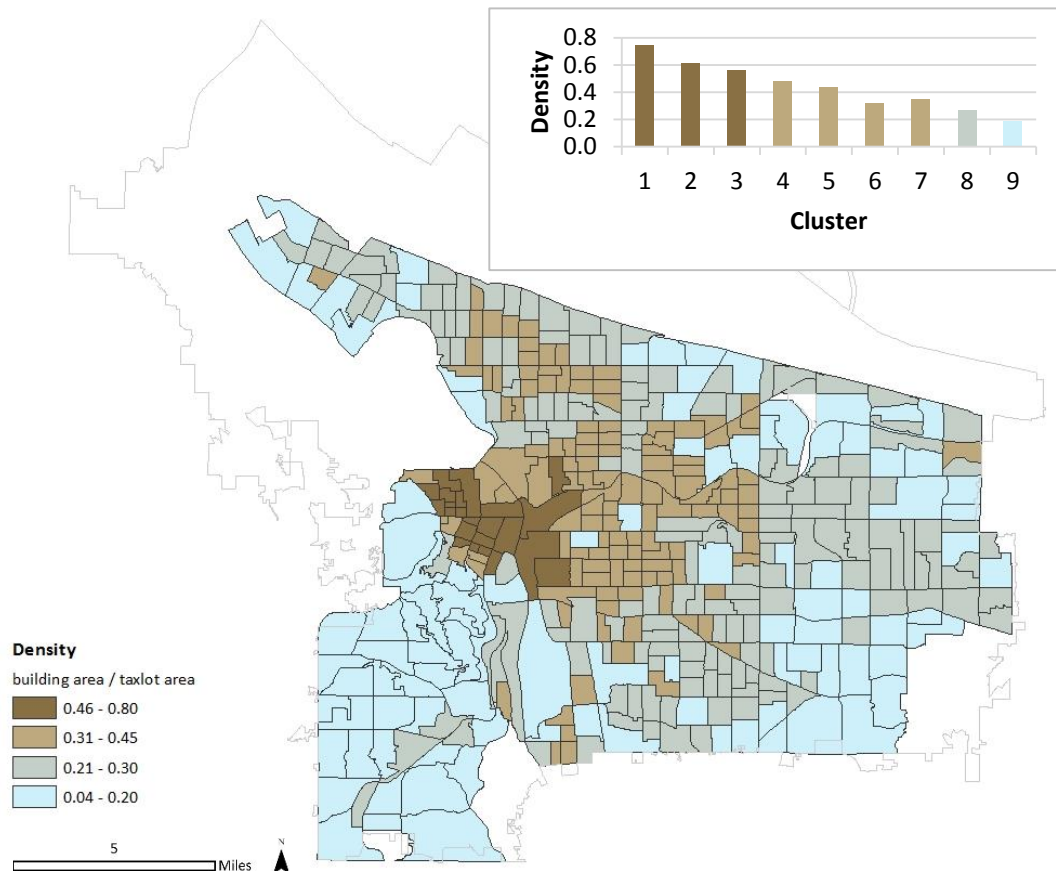


Figure 4.4: Density, distribution by geography and cluster

Among those features affecting density, city parks, cemeteries, natural areas, and college campuses appear the most striking. While the central city generally lacks areas of greatly reduced building density, it is evident that those neighborhoods near one of these “open” features would naturally differentiate themselves from their denser neighbors.

Massing explains the size, height, and overall bulk of the structures found within an area. This metric measures the ratio of the average total square footage of structures and the area of the property parcel within each census block group. Massing

ranges from 0 upward, with those areas of greatest massing having the greatest numeric value.

Massing differentiates areas of tall, bulky structures from sprawling shorter developments, more thoroughly illustrating the size of structural solids found within the greater urban void. Since massing summarized the total square footage of each floor, not just first floor foot prints, many areas demonstrate massing of greater than 1. In these instances, an increased massing suggests the presence of large or tall multistory developments, on properties with relatively little or no open space (Levy 1999).

In Portland, the greatest concentration of massing lies within the central business district (see figure 4.5). Most of the city's tallest and most massive structures reside within one of seven census block groups. Much as density suggests, these areas are among the most intensely and longest settled within the city, areas first developed by Anglo-American pioneers, decades before Portland's founding (Oregon Historical Society 2002). The surrounding neighborhoods also demonstrate the presence of significant and consistent structural massing.

With the exception of areas of challenging terrain, massing drops precipitously but continually from downtown Portland outward toward the city's boundaries. Massing appears to be influenced by the presence of primary roadways, namely freeways and arterial boulevards. The Lloyd District of inner northeast Portland and the

neighborhoods surrounding Providence Medical Center near the city's geographic center remain two areas of note, both near major freeways and roadways.

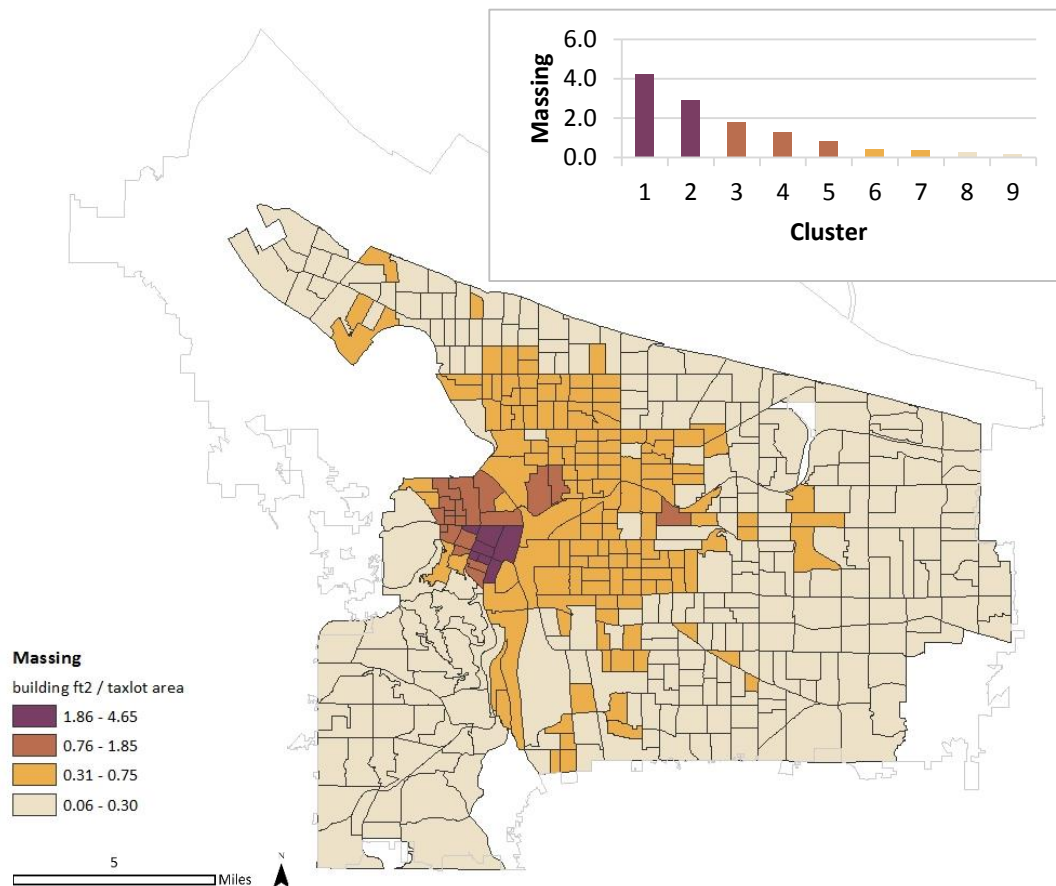


Figure 4.5: Massing, distribution by geography and cluster

Accessibility, density, and massing appear interrelated. While areas of high massing also exhibit higher density, these same areas demonstrate higher levels of accessibility (see figure 4.6). As the accessibility of an area declines, massing and density also decrease. This trend is observed across all nine cluster categories, with the noted exception of cluster 7, and to a lesser extent cluster 8.

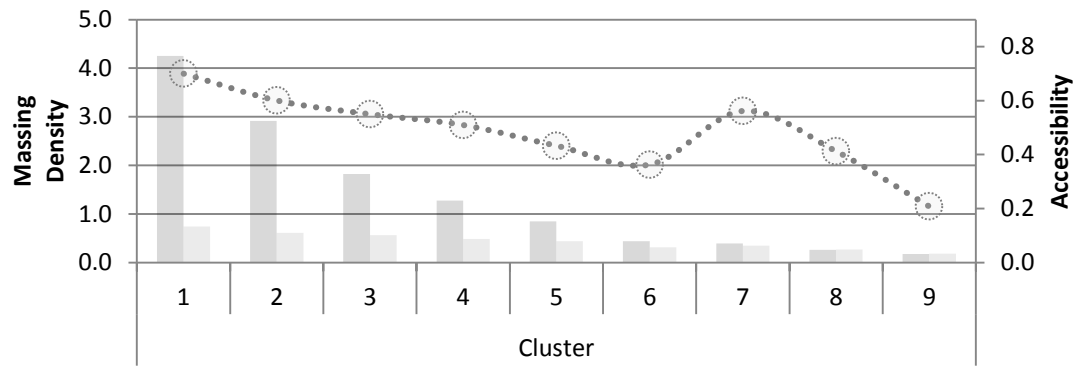


Figure 4.6: Metric trends

Compare against each other, the metric trends reveal a specific relationship between the accessibility of a location and the intensities of its land uses. Massing expresses an exponential decay from cluster 1 outward toward cluster 9. Like massing, the near linear decay of density across the clusters also supports the concepts of centralization, those suggesting urban growth as radiating outward from a primary downtown core (Knox et al. 2011, Rodrigue 2016). While irregular, a generalized accessibility trend also decreases outward through the nine clusters. Extreme values of accessibility correlate with those of massing and density respectively, despite intermediate irregularity. The implications of these exceptions and trend outliers are explored in the following sections.

### Analysis of variance

SPSS k-means analysis include a report of analysis of variance (ANOVA), a comparison of the differences between the cluster category means (SPSS 2016). A one-way ANOVA compared the variation of the values between the census block groups, and

for each of the three metrics of analysis (accessibility, density, and massing) as well as within each of the census block groups. For the ADaM cube comparison, k-means returned an ANOVA demonstrating p-values of 0, revealing that the statistical significance between each of the census block groups are not equal (see table 4.2). This indicates that not only do the values between census block groups differ, but that the variances of each of the three metrics (massing, density, and accessibility) within each individual census block group remain consistent. ANOVA results suggest that the clusters resulting from ADaM cube analysis provided a sound categorization of all 418 census blocks groups into nine defined form category clusters.

Table 4.2: ANOVA output, form clusters and categories

ANOVA						
	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
accessibility	1.079	6	.004	404	243.347	.000
density	.400	6	.002	404	192.958	.000
massing	3.309	6	.004	404	837.702	.000

### Spatial statistics

Referencing the spatial statistics tools of ArcGIS, the geographic distribution of the ADaM clusters was also examined. Global Moran's I compared the locations and distances between census block groups, as well as the classification provided by the cluster group categories (ArcGIS 2016). This tool analyzed the geographic pattern resulting from k-mean analysis, establishing if this pattern was clustered, dispersed, or

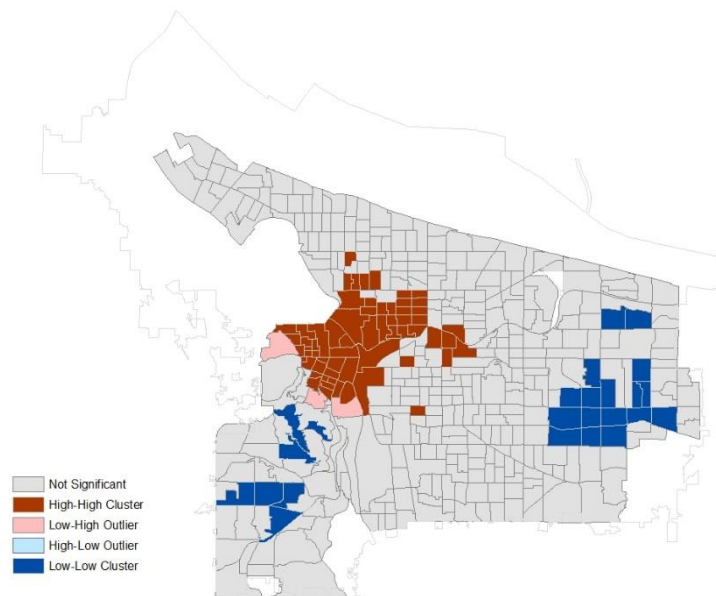
random. Global Moran's I determined that the nine category clusters resulting from k-mean exhibited a clustered pattern, with "p-values" of 0 and significant positive z-scores (see table 4.3).

Table 4.3: Global Moran's I summary, form clusters and categories.

Global Moran's I summary	
Moran's Index:	0.995639
Expected Index:	-0.002398
Variance:	0.000423
z-score:	48.502284
p-value:	0

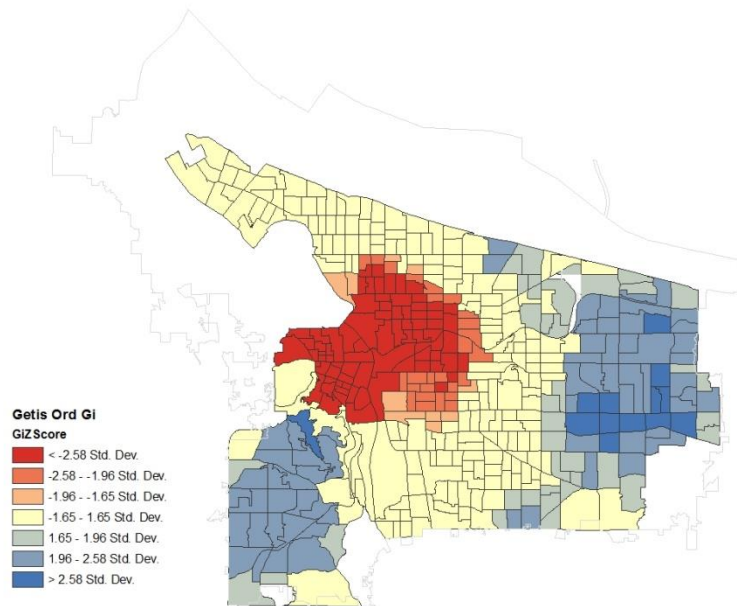
Helping to further examine the spatial distribution of geographic clustering, the tools for mapping cluster in GIS provided additional explanation. While Global Moran's I determines if there is significant clustering, Anselin local Moran's I demonstrates how and where. This tool is useful in not only showing the location of similarly valued cluster groups, it also demonstrates where sharp transitions take place (Low-High for example), as well as large areas of more gradual transition between high concentrated clusters (see figure 4.7).

Figure 4.7: Anselin local Moran's I, cluster relationships



Local Getis-Ord Gi identified statistically significant areas of high or low values, otherwise known as “hot or cold spots” among the census block groups (ArcGIS 2016). Tracing both the distance between neighboring groups as well as their cluster categories, this tool determined if ADaM cube values are clustered predominantly in high or low block group, illustrating the both extremes, as well as “areas of transition.”

Figure 4.8: Getis-Ord Gi, geographic clustering of form



This tool provides a “z-score” for each of the census block groups, indicating areas of similar values as well as describing the standard variation of values found within all census block groups. For this research, the local Getis-Ord Gi analysis was performed on the ADaM cube value and building era value. High z-scores suggest a high concentration, or hot spot of the densest, most massive and highly accessible areas of Portland, Oregon. Low z-scores indicate areas of the lowest land use intensities and transportation accessibility, while z-scores between these two extremes suggest transition, or a mix.



A distance is chosen for this process that ensures that several neighbors are available to compare each of the census block groups against. Through several iterations, a distance of 1,000 feet (roughly four to five downtown city block lengths) appeared as the most ideal for the research scale. Additionally, a zone of indifference band was chosen, specifying that those census block groups directly neighboring an area provided a greater impact than those further away.

The results of Getis-Ord Gi were further simplified and compared against the average building year of each of census block groups' structures, otherwise known as era. This association provides further insight to the age and chronology of urban development, as well as providing a sense of urban progression (see figure 4.9). With few exceptions, the oldest, densest, and most massive areas of the city exist at the urban center, while newer less intense construction occurred outward and over the course of several decades. These results help to illustrate urbanization as a process, suggesting the causes if not context that's led to Portland's current urban landscape.

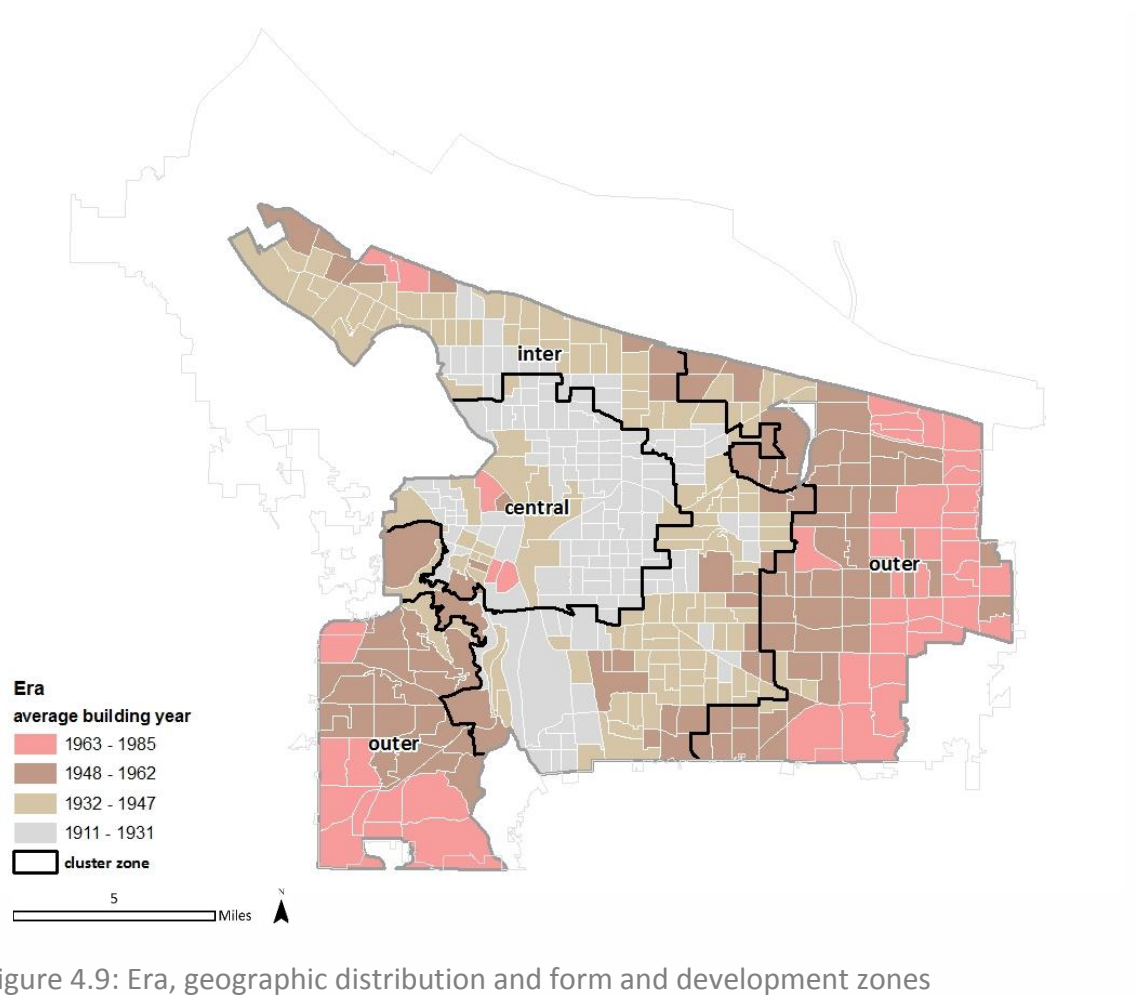


Figure 4.9: Era, geographic distribution and form and development zones

## 5: DISCUSSION

### Typological comparison

The following sections establish local context for each of the urban form typologies found in Portland, Oregon. Figure 5.1 provides the location of provided examples. Three generalized categories, core, transition, and suburb groups, help to organized forms with similar characteristics and geographic extent.

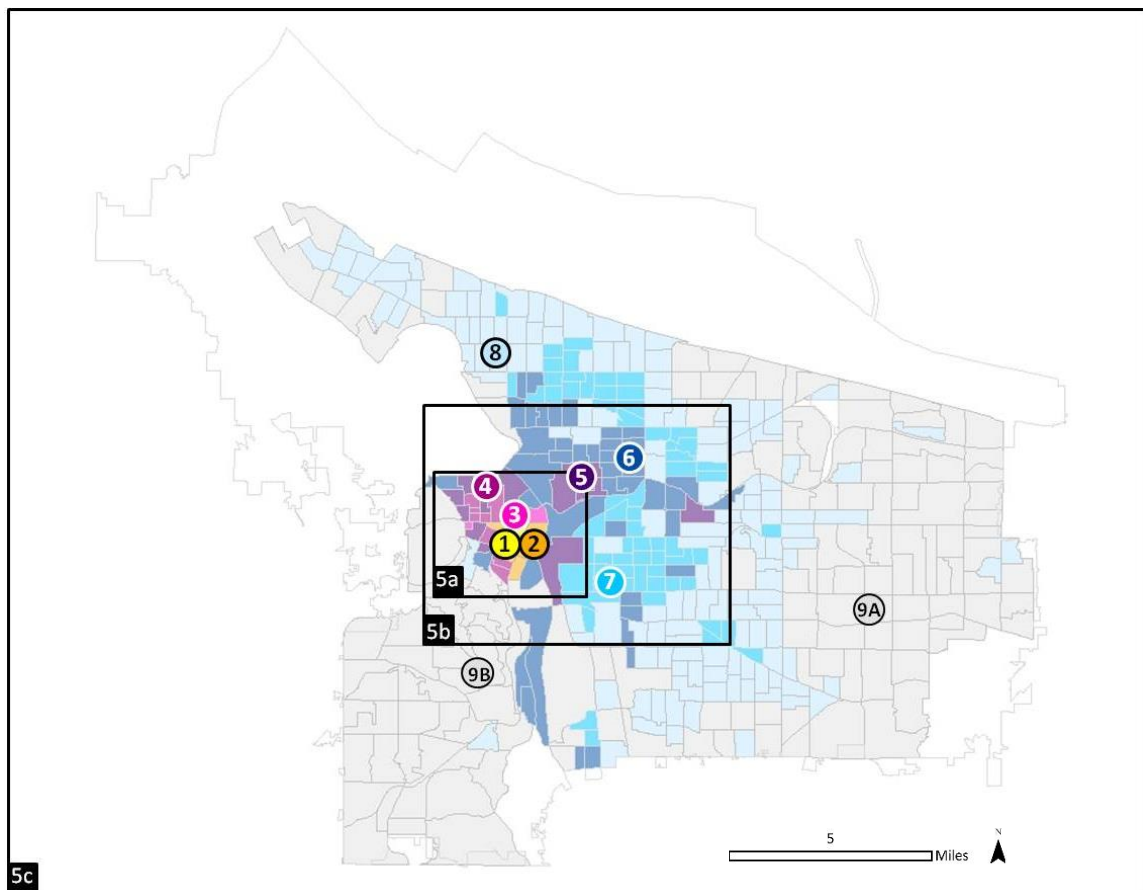


Figure 5.1: Typologies, case study locations

## Core Groups

At the heart of Portland's central business district two clusters, groups 1 and 2, represent the city's densest, most massive urban developments, and are among its most accessible neighborhoods. Home to the majority of the city's tall buildings, including the seven tallest, these groups also host the Portland's tightest and most complete street grids. These "core groups" characterize the city's primary urban center, the point from which the demands of development and real estate radiate outward. The intensity of land use is evident, with 60 to 75 percent of all land dedicated to structures (see figure 4.4). There are notable differences between the two groups, and history explains this separation.

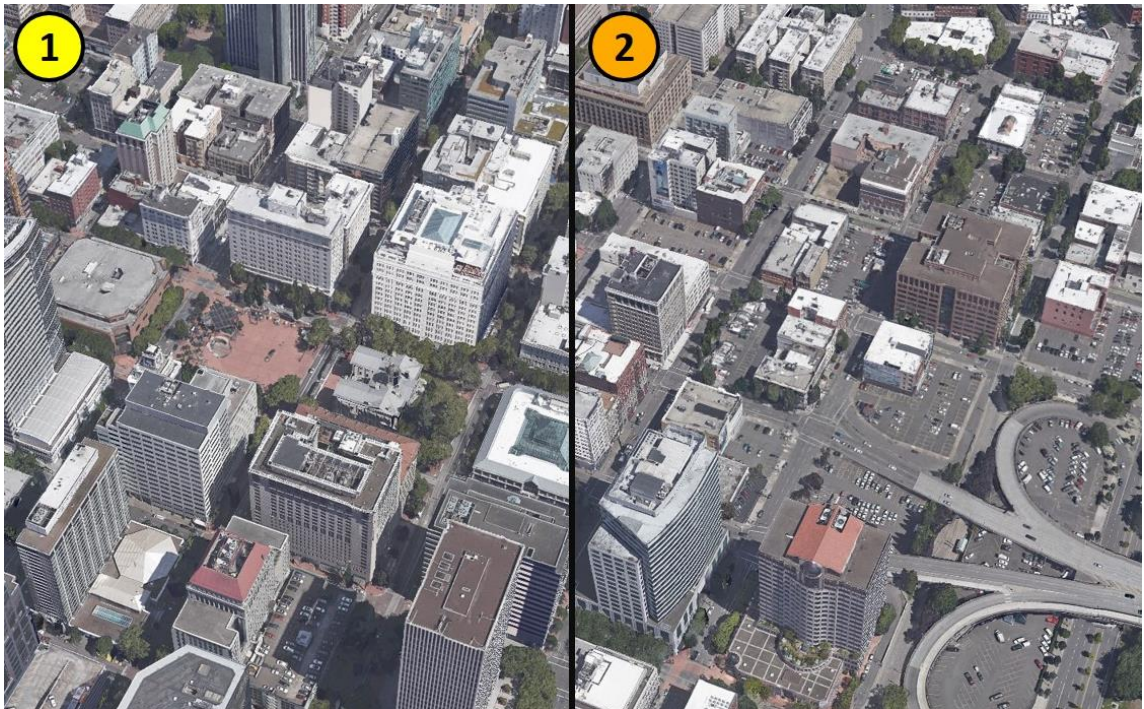


Figure 5.2: Core groups: Tower (1) and patch (2) (Google 2016)

The core groups are located within the original city incorporation, neighborhoods settled and urbanized over the last 150 years (Oregon Historical Society 2002; see figure 5.3). The pressure of these areas to develop and redevelop is due in part to location. At the hub of the mid-19<sup>th</sup> century trade network, very few of the city's original structures or even infrastructure remains, falling subject to considerable increases in population, demands for space, and changes in technology and primary industries (Price 1987, Abbott 2011). Though the wharfs and original plank roads are lost to history, the grid and tight block size persists, leaving a highly accessible transportation network in place.

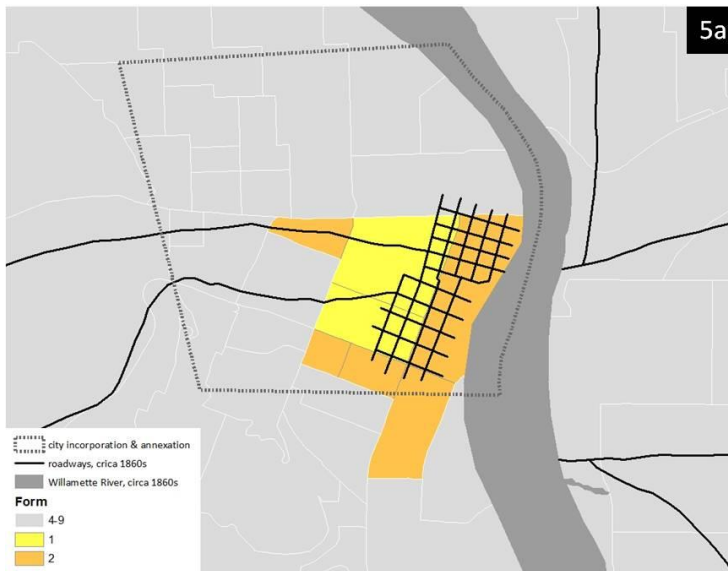


Figure 5.3: Core groups and original settlement (inset 5a)

The most striking distinction between groups 1 and 2 visually is the scale and frequency of heavily developed urban blocks (figure 5.2). A collection of *towers* and densely occupied properties define group 1, a mixed composition of early 20<sup>th</sup> century

high-rises and later century tower plazas. The *patches* of group 2 represent an assortment of remnant brick low-rise construction, open asphalt lots, and isolated collections of newer office buildings.

### Transition Groups

Outside the core, groups 3, 4, and 5 occupy an interurban zone, resting between Portland's center and its outer reaches. These "transitions groups" are defined by divergence, acting as thresholds between citywide extremes. Here the differentiation between each neighborhood, even neighboring blocks and structures, is at its most pronounced (see figure 5.4). Nowhere in Portland are the impacts of freeway construction and urban renewal most evident, particularly at such scales. All three groups are bound, linked, or transected by freeways, though the consequence of these adjacencies varies greatly between each group (see figure 5.5).

Only two census block groups appear in group 3, but these areas represent simultaneously the oldest and newest developments in the city. Though the density of this group remains constant, structural massing varies greatly between blocks and neighboring groups (figure 4.1, figure 5.4). Adjacency to the urban core and relatively high density demands give rise to increased massing, growing from a well-connected and accessible street grid. As *transect*, group 3 demonstrates a wide variation, or cross section of structural age, form, and land use function, spanning the width of the central business district, and linking the core the other transition groups (see figure 5.5).



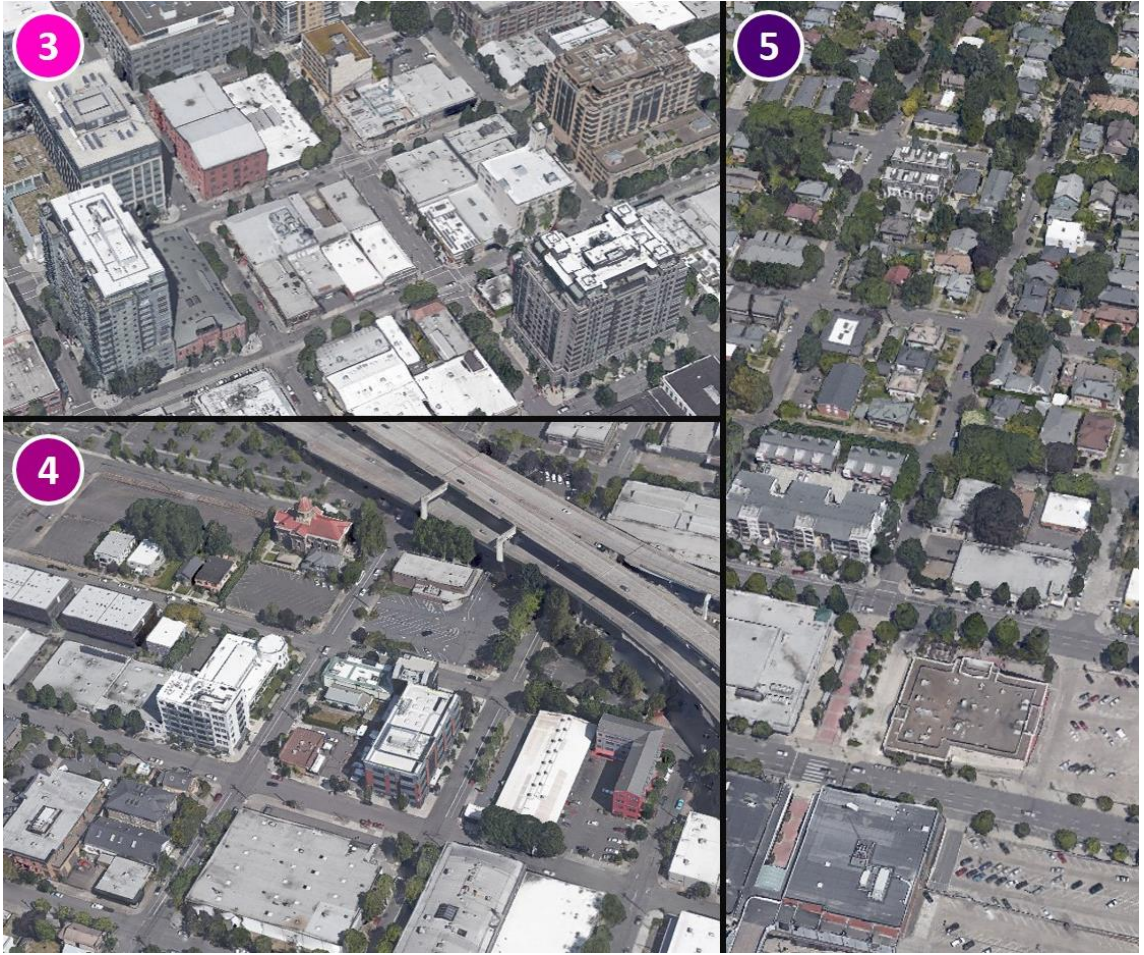


Figure 5.4: Transition groups: Transect (3), portal (4), and renewal (5) (Google 2016)

Interspersed within the heart of central Portland, group 4 represents an era coinciding with vast changes of ideology and economics. Urban renewal and the arrival of the Interstate Freeway System greatly transformed urban centers like these (Ford 2003, Knox 2011). Multi-lane highways, on ramps, and parking lots ring Portland's central business district, acting as *portals* and arrival points for the urban core (see figure 5.4). An agglomeration of remnant homes and warehouses, mid-century auto-oriented offices and retail, and institutional campuses define this group.

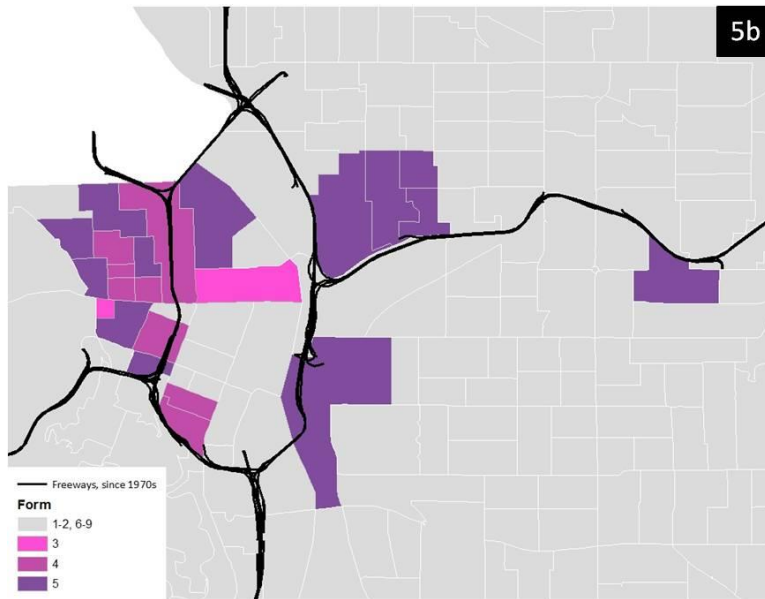


Figure 5.5: Transition groups and area freeways (inset 5b)

Group 5 buffers the tumultuous forces of the urban core from the generally low intensity outer reaches of greater Portland. The group overall remains relatively dense and massive, though exhibits lower accessibility despite abutting freeways (see figure 4.6, figure 5.4). The isolated high-rises and campuses of group 5 are balanced by an expanse of surface parking, low-slung retail, manufacturing, and apartment buildings. This group owes much of its form to a legacy of urban *renewal*, a process marked by the reorganization of urban space through the near complete destruction of previous urban forms as well as the existing street grid. The results offer a stark contrast between more intense land uses among otherwise older, single family residential neighborhoods.



## Suburban Groups

More distant from the core and stretching to the city's boundary, groups 6, 7, 8, and 9 represent those areas of the least density, and massing. However, these four “suburban groups” have a mixed relationship with accessibility, each developing in respect to specific modes of transportation, demonstrating unique spatial organizations in relationship to particular infrastructural investments.

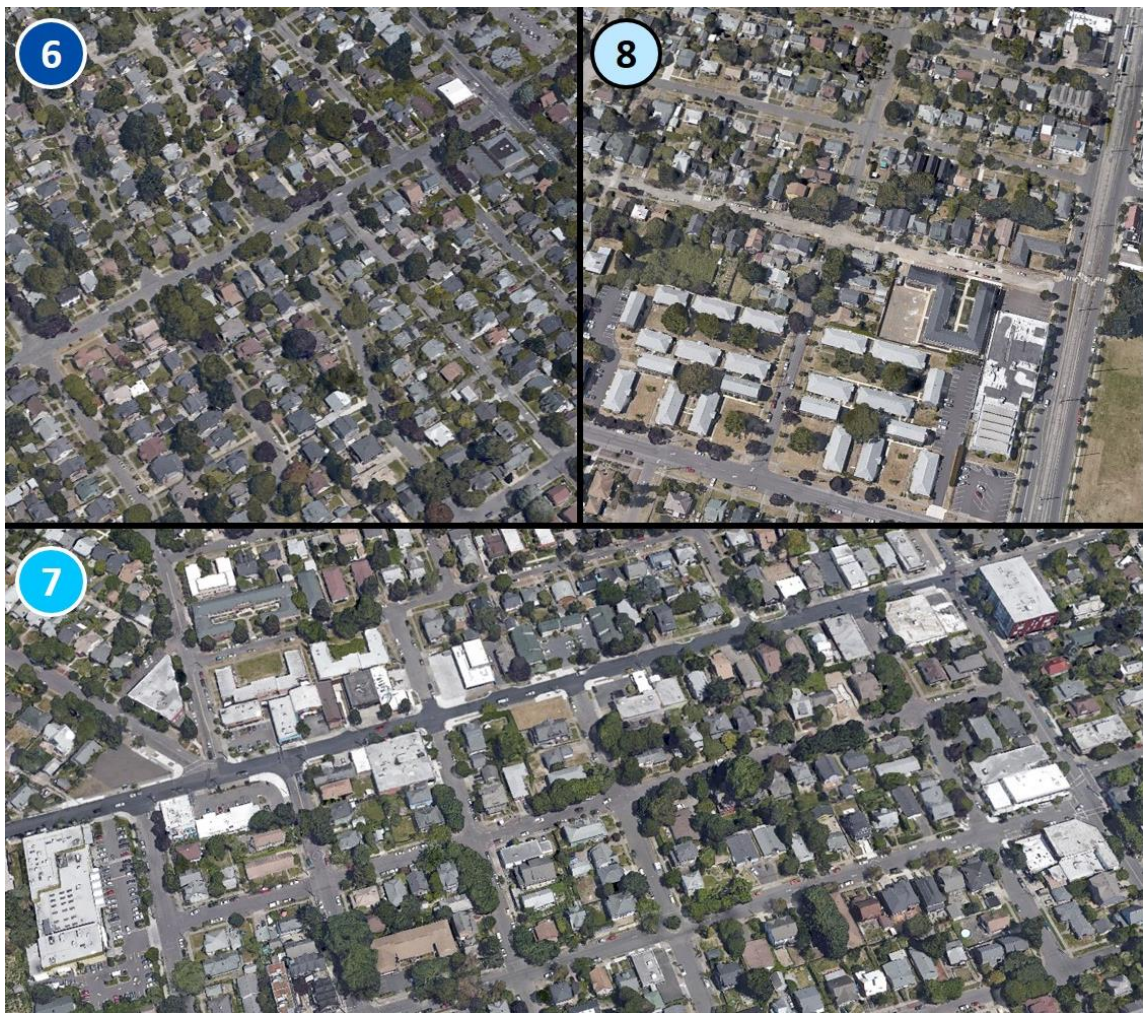


Figure 5.6: Suburban groups: Annex (6), main street (7), and side street (8) (Google 2016)

Group 6 continues two trends seen in all previous five groups; gradual decreases in density, and a consistent drop in accessibility. In this group, the precipitous loss of massing begins to flatten, as neighborhoods appear to have near-equal amount of building square footage to property parcel area. Located just beyond Portland's more intensely developed central neighborhoods, group 6 serves as a development *annex*, an extension of those patterns seen in previous groups. Here structures and property meet space/structure equilibrium. This group appears to house many of the city's denser, older two story single-family residential neighborhoods (see figure 5.6).

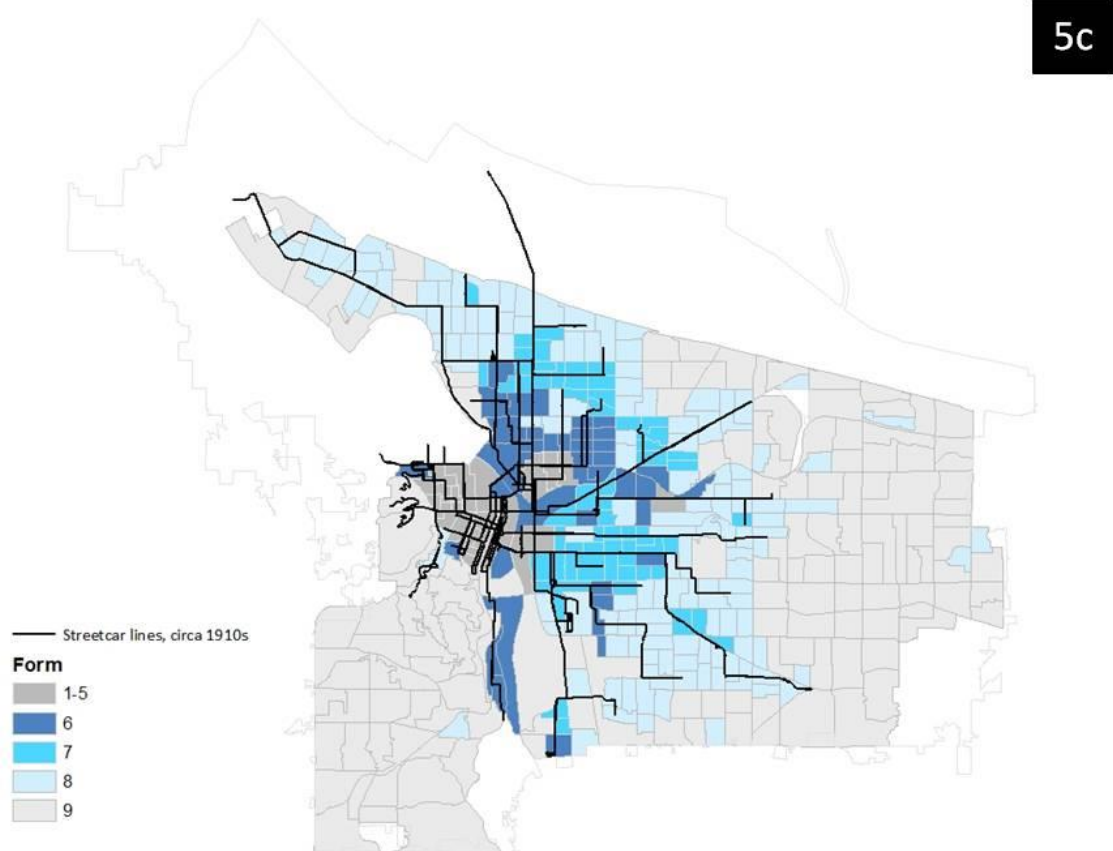


Figure 5.7: Suburb groups and early streetcar system (inset 5c)

Like group 6, the balance of massing and density, structure and space, continue to persist in group 7. Accessibility distinguishes this group however, with values greater than any of the suburban or even transition groups before. Areas in group 7 are most often found alongside and between former streetcar routes (see figure 5.7). These neighborhoods appeared with the introduction of streetcars, and developed with tightly grided roadways parallel to retail *main streets* (Oregon Historical Society 2002; see figure 5.6). Though highly accessible, most development remains less intense.

On the far edge of the distance spectrum, group 8 represents those areas built toward the end of streetcar prominence. These neighborhoods are more openly spaced, built off of main thoroughfares on narrower but less frequent and less intensely developed *side streets* (figure 5.6, and figure 5.7). Together, groups 6, 7, and 8 developed as streetcar suburbs, taking advantage of rapid overland travel unavailable generations earlier (Fyfield 2003, Abbott 2011). These groups concentrate closely to arterial roadways, generally within a half mile of a former streetcar line.

As the least intensity developed, nearly one third of all census block groups are in group 9 (see table 4.1). Characterized by very low accessibility, these areas comprise the city's vast urban *edge* (see figure 4.1, figure 5.8). Currently this group contains nearly all of Portland's most recently developed and annexed neighborhoods, developing around automobile exclusive infrastructure (Bureau of Development



Services, The City of Portland 2016). Whereas other groups evolved from the alteration of previously developed neighborhoods, group 9 represents urban expansion. This edge has simultaneously expanding outward while its inner regions have either become isolated or reorganized amidst urban redevelopment.

Despite similarities of form and accessibility metrics, group 9 is best understood as two distinct geographic subgroups. East Portland owes its transportation network to decades of isolation from the inner city, as well as annexation in more recent decades. Broken grids, dead ends, and long block lengths limit the number of intersections, and thus accessibility (see figure 5.8). The topography of southwest Portland on the other hand proves challenging for transportation infrastructure. Long curved roadways, branch-like street networks, and meandering thoroughfares disrupt the network's grid (see figure 5.8). Through different means these subgroups produces a similar end, low accessibility, while less intense land use combinations of widely spaces homes, low-rise apartments, strip malls, and semi-agrarian land uses are not uncommon.



Figure 5.8: Suburban groups: Edges (9) (Google 2016)

## Evaluation

Pulling from decades of urban observation and spatial study, this research outlines a methodological workflow, tracing the growth of Portland, Oregon, and expanding the tools of spatial evaluation. Grounded in theory and backed by the power of GIS and statistics software, the ADaM cube incorporates the most basic elements of form, demonstrating principals of urban spatial theory within a localized context.

Beneath their surface, the form typologies produced by this research represent the deeper complexities of urbanization, revealing the importance of spatial interaction in the shaping of urban spaces. Drawing from differences in adjacency, dimension, and distance, urban form demonstrates the progression of development, and the gradual momentum of urbanization. Urban environments exist as the result of these amalgamations, the consequence of all past investments, and influenced by the travel patterns occurring within and between them.

Observed over time and across the landscape, form typologies also illustrate the trajectory of development (see figure 4.9). In over a century of growth, transportation has influenced the shape of Portland's development, which in turn has facilitated the continued development and evolution of transportation systems (see figure 5.9). The distinctions among different urban environments communicate not only how this relationship has guided Portland's physical growth, but how this interaction has

supported existing relationships and travel, as well as reinforcing land use functions and continued development.

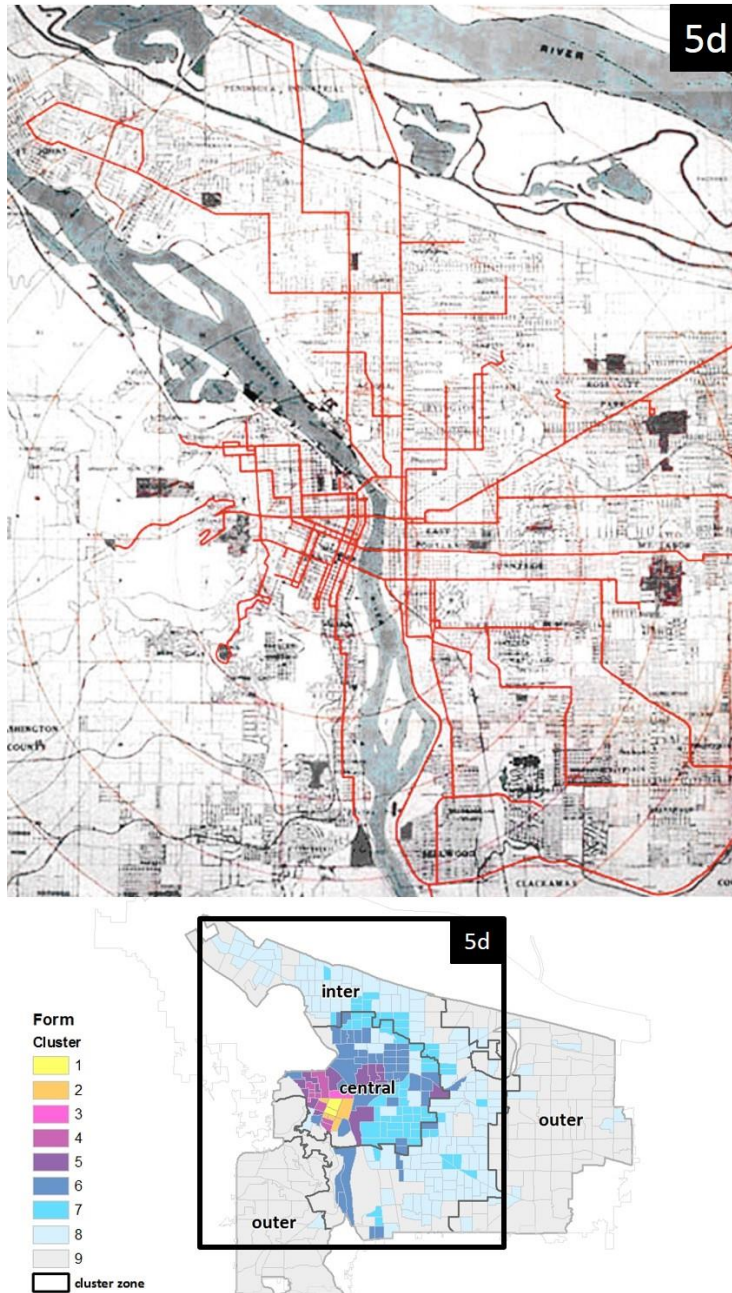


Figure 5.9: Roadways and streetcar network (1912), and Portland’s form and zones of development (2016) (City of Portland Archives 2016).

## Implications

Form categories reveal the city as it is, but also what it may become. The ADaM cube, while essential in categorization, may also demonstrate what changes would occur should values alter. For example, the proposal of a new development within an existing census block group may fundamentally alter the form of this group, should current low intensity properties redevelop as dense massive structures. This exercise is even more significant as compared to accessibility, if for example an area's high accessibility would suggest and support more intense development.

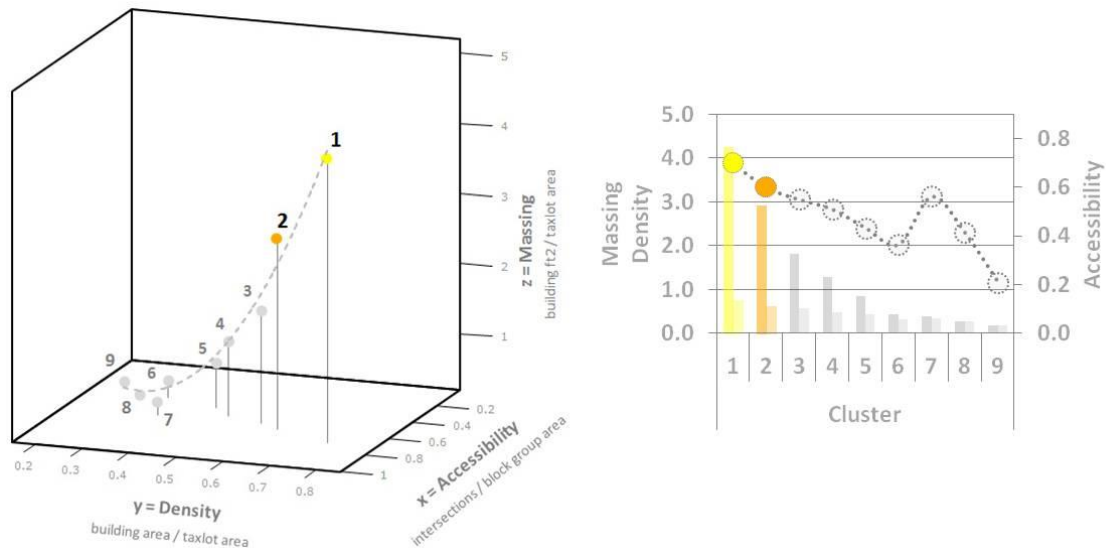


Figure 5.10: Core groups, density and massing comparison

In the case of downtown Portland's group 2, lower accessibility, density, and massing distinguishes this area from group 1 (figure 5.10). Five census block groups are represented in group 2, but taken in isolation individual census block groups appear more similar to those found in the group 1 cluster (table 4.1, figure 4.1). For example,

those blocks found to the east of the central business core exhibit a continuation of the tight roadway grid, but currently lack intense development (figure 5.2).

The patchwork developments of group 2 are the consequence of decade's long urban renewal, automobile proliferation, and changing economic priorities (City of Portland Archives 2016). Like other North American cities, sections of Portland's downtown core experienced very intense, high-rise redevelopment, while others accommodated the influx of automobile traffic, redeveloping instead as parking lots, garages, and drive-through retail (Ford 2003, Know 2011).

Though portions of the central business district lost structures, most of the street grid survived this reorganization. Upon this patched urban canvas, developers have proposed incremental but very intense high-rise redevelopment (see figure 5.11). As the accessibility this census block group suggests, these proposals are not only appropriate given the area's strong urban grid, but research methodology implies that they are to be anticipated given the positive relationship between intense development and high accessibility. Like decades before, the tightly bound grid of downtown Portland may again support an influx of intense high-rise construction.





Figure 5.11: Core group 2, current (5e) and proposed (5f)  
(Downtown Development Group LLC 2016)

Drawing further conclusions from research data, the ADaM cube and form map reveal anomalies outside the expectations of metric trends, or observed citywide patterns of development. Among the most significant implications of the research methodology are the data outliers. Group 7 appears as the most striking example, with some of the most accessible census block groups citywide, yet demonstrating very low intensity development (see figure 5.12).

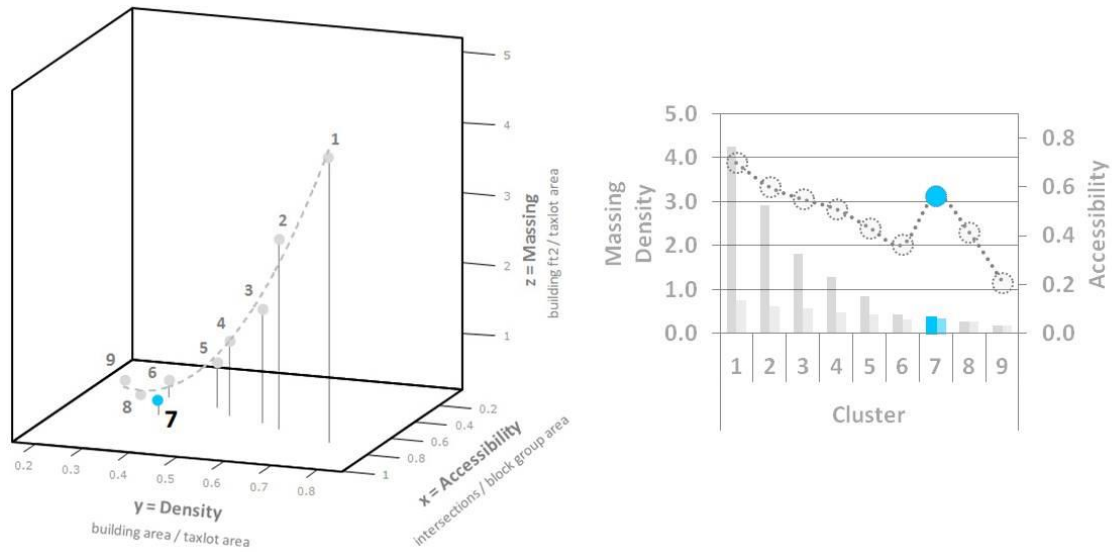


Figure 5.12: Suburban groups, accessibility outlier

The implications of these anomalies are significant, strongly suggesting the potential of intense redevelopment of large areas of central Portland. Within group 7, 61 different census block groups are spread almost entirely throughout inner Northeast and Southeast Portland (see table 4.1, figure 4.2). Since accessibility and dense, massive development are strongly related and appear to support one another elsewhere, group 7 has the potential to change urban form dramatically. Large areas of group 7 are zoned for higher density, taller structures than those existing currently. These “upzones” are prescribed in both current code, and are continued if not expanded in future planning efforts (Bureau of Development Services, The City of Portland 2016; see figure 5.13). “Walkability,” or the ease of pedestrian or cyclist travel afforded by short block lengths and tight street grids, helps to accommodate denser, taller, and less automobile-dependent development forms (Portland Plan 2016).

Areas of group 7 rezoned for higher densities have witnessed rapid and dramatic changes to localized urban form. In the years leading to and during the 2008 Recession, construction of multifamily and mixed-use commercial and residential structures accelerated (Bureau of Development Services, The City of Portland 2016). The most intense developments have typically concentrated along arterial roadways, for example SE Division St. between 28<sup>th</sup> Ave. and SE Cesar E Chavez Blvd (see figure 5.13, figure 5.14). These developments have coincided with improvement to roadway, sidewalk, and bicycle infrastructure (Portland Bureau of Transportation, PBOT 2016).

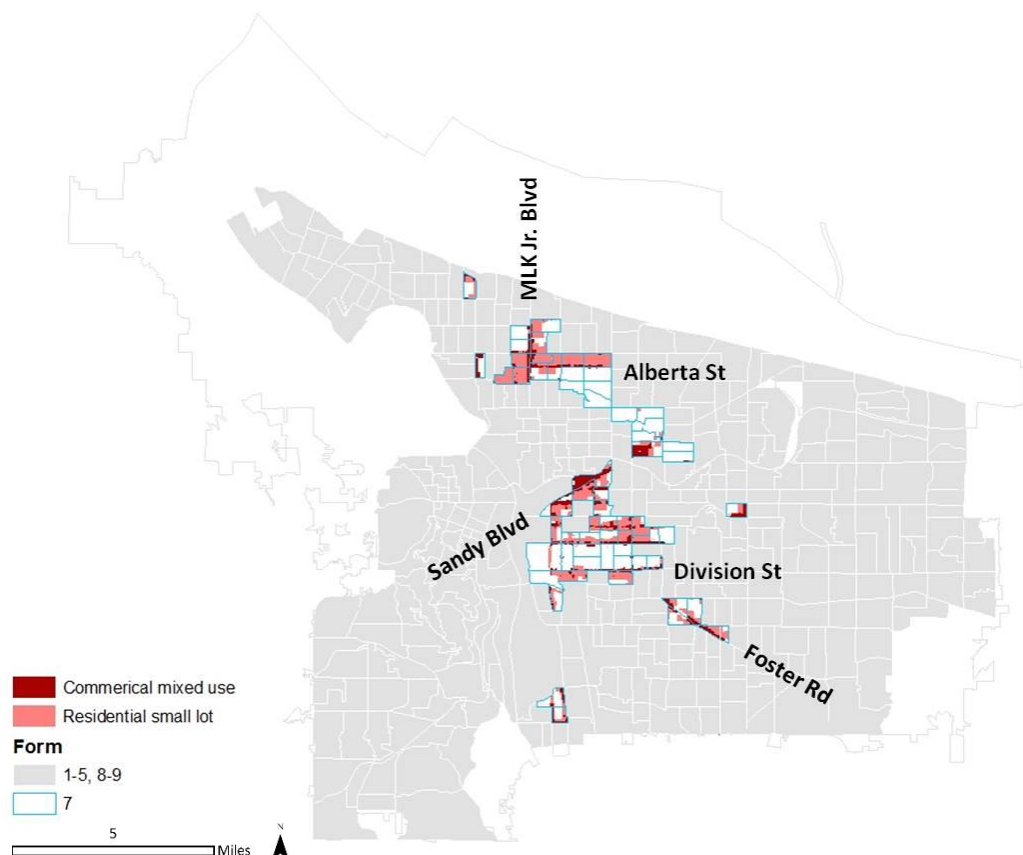


Figure 5.13: Suburban group 7, and mixed use and small lot zoning



Figure 5.14: Zoning, mixed use corridor development in group 7 (Division St. at 31<sup>st</sup> Ave.) 2009 (5g) and 2015 (5h). (Google 2016)

Lot subdivisions have also hastened. Much of group 7 exists within the R2.5 zone, allowing for the separation of lots of 5,000 ft<sup>2</sup> or greater, the current and standard size for much of the city (Bureau of Development Services, The City of Portland 2016). This commonly results in the doubling of residential density, and renders smaller lot sizes (Bureau of Planning & Sustainability, The City of Portland 2016; see figure 5.15). Zones like R2.5 occur throughout neighborhoods, and are not necessarily exclusive to



arterial roadway adjacency. As a result increased density is gradually distributed throughout a neighborhood, as is the case near NE Alberta St. (see figure 5.15).



Figure 5.15: Zoning, residential density increase in group 7 (21<sup>st</sup> Ave. at Alberta St.) 2009 (5i) and 2015 (5j). (Google 2016)

In time, areas of group 7 are likely to alter, and result in either the re-categorization of census block groups, or the creation of an entirely new class of urban form. If changes are significant enough and unique beyond the current catalog, the ADaM cube helps to recognize the emergence of Portland's next development phase.

Though group 7 stands out among the nine form groups, most categories do not suggest the impending alteration of the greater urban landscape. These categories are instead responsive to the city's current form, and the designation of census block groups from one category to the next will likely change over time. Should the physical characteristics of a neighborhood alter enough, re-categorization is the logical result. However, as group 7 may yet demonstrate, future challenges to the current paradigm may provide for the reexamination of form, suggesting entirely new categories.

As theory and research suggest, each of the ADaM cube metrics are invariably linked, and have the tenancy to draw one another into balance. For areas of the city lacking any one of these metrics, it is challenging if not impossible to enforce the direct re-development of neighborhoods without maintaining proper metric ratios. For instance if group 9, the outer-most sections of Portland, are to ever resemble the central city, increased density and massing alone are not be enough. Increased transportation accessibility, through either the large scale property acquisition in East Portland and significant bridging and earthwork investments in Southwest Portland would be necessary should the basic patterns observed in the central city be realized elsewhere. The ADaM cube, while dynamic even suggestive, must be used with caution. The "likeness" of urban form, perhaps emulated, is not a formula for "sameness."

## **6: SYTHESIS**

### **Limitations**

The research methodology is subject to a number of limitations. In post-processing investigation, the finalized ADaM cube is strictly speaking an interpretive tool. Though essential in the creation and presentation of form categories, its use as a predictive model is limited to deduction and implication based upon input data. Currently the results of this methodology are static, representing a single instance in Portland's urban timeline. While possible based on the current model design, conducting change analysis would require a series of data for each census block group and for each of the three metrics. Additional workflows would be necessary to compare and to record the statistical significance of any observed changes.

This research methodology is also limited by the quality of data available, including the age of this information, and the frequency of updates. Temporal consistency is another limiting factor, ensuring regularity among various datasets. For Portland, these data are publically accessible, and cycled annually, though GIS data is unreliable for this model before 1996-97 (Regional Land Information System 2016). However, all recently-created data meets the proper standards, scope, and extent specified by this model. Applying the research methodology in other cities would require the same types of GIS features specified in data processing, and careful examination of census block groups for appropriate land use areas. The basics of the

data processing workflow would remain viable, though alteration to query statements or pre-processing data edits may be required from any potentially new data sources or scopes.

The metrics of this research lack fine detail beyond the scope and capabilities of these research tools. Though useful in establishing basic urban morphological categorization, urban form is the consequence, of a continual anthropogenic enterprise; cities are and have always been an expression of the human condition. On their own, the ADaM cube, GIS programs, and every map conceived exist as representations, never complete, often isolated, and inherently biased. But among the greater, multifaceted, and likely persistent study of urban environments, this research method functions as one of the many tools necessary to more fully illustrate the character of urban spaces.

### **Methodological assumptions**

This research subscribes to a number of assumptions, among them distinction between causation and correlation, as is the case in statistical analysis. Further, similarity does not make for “sameness,” and observed phenomena are not necessarily replicable. For instance, urban form derived from the context of a specific place and time likely will prove difficult to reproduce elsewhere in the present. Spatial associations may be the result of unforeseen or hidden interactions as well, making for relationships beyond the scope of this study (Paez et al. 2005). Though the overriding rationale of urban development may be traced to transportation accessibility, the



idiosyncrasy or character of place may be lost in research conclusions (Crane 2000).

Again, supplemental media is necessary to understand the sensitivity of context.

Since data is represent through the classification of census block groups, results may incur bias under the modifiable areal unit problem (MAUP). The aggregation of accessibility, density, and massing metrics into block group boundaries not only generalizes urban form across several city blocks, the block groups themselves vary in size across the research's geographic extent. However, most centrally located census block groups demonstrate similar shapes and compatibles areas, while larger and more irregular examples are found most often near the edges of the research extent. Additionally, census block groups not only retain some sensitively to the locations they are drawn from, they are and more widely available units for urban areas, providing localized scale but also wide spread applicability.

Lastly, the generalization of distilled values from discrete information is used to establish common metrics and spatial comparison in analytic software. It is not the intention of this research to suggest a formula for "place," but instead to convey the basic relationships of spatial/temporal contexts. With such a foundation, further examination, experiment, and research may be possible.

### **Validity**

With regard to research scope and topic of focus, analysis and narrative are imbued with inherent design bias. Literature review, historic research, and experience

with GIS techniques heavily influenced the development of this research.

Understanding these limitations however, it is recognized that many subjects are ultimately omitted in this research, their absence best explained through comprehensive review of theory and demonstration of results. For example, while several important considerations may result in a particular urban form (policy, resources, economics, etc.), spatial analysis suggests strong connection to an overall reliance on accessibility and transportation infrastructure.

The creation of categorized urban forms is also potentially very subjective as well, and risks the alienation, misrepresentation, or symbolic invasion of intimate, individual, or otherwise “sacrosanct space” (Relph 1976, Cresswell 2015). Whereas research analysis provides the basis of categorization, additional explanation is necessary to reinforce the narrative of experience, or better illustrate places beyond spatial metrics or generalized analytics.

### **Suggestions**

Refinements to the basis workflow, or the addition of new attributes could be another area of improvement. For instance, transit or bicycle infrastructure, even roadway type, size, or lane width and speed could play a role, providing for the detail accessibility with the base model. The nuances of zoning may help to distinguish “inter-group” dynamics, detailing localized interactions and scales. These details may provide for a more robust, detailed planning model.

Though the research metrics focused on a limited number of attributes and spatial features, the areal units selected for study are embedded with demographic information. Census block groups focus on human interaction and composition, and contain data for population, income, and race among others (Regional Land Information System 2016). Chosen for this research due to their smaller and generally consistent size, these units are also the most detailed public available census information (Regional Land Information System 2016). Building off of the research model, these data may be applied in conjunction with urban form, and provide the basis for more detailed *demographic study* in specific urban spaces.

Since demographic data for census area are updated annually from the American Community Surveys, demographic and form research may compare changing conditions over a series of decades. *Change analysis* could focus on the alteration of form more generally, observing the shifting of categories, or the creation of new form types. Conversely, urban alteration may offer a more comprehensive narrative when paired with demographic data. For instance, particular form groups may have correlation with income, education, or even race. How these forms alter, and what social groups are ultimately affected, would provide for potentially valuable information, informing public dialogue in future planning efforts. Census information however is typically available in census tract sizes. Aggregated data and more generalized extents would need to be considered with these larger census areas.

Similarly, development proposals and simplified roadway and structural information could be applied within the ADaM cube. This study would provide a baseline and projection of how form would change in response to new or altered development. Several iterations would provide a range of options, based upon existing form and desired outcome. This same model could apply towards other locales, helping to determine how places differ, what changes have occurred, and who is most affected. The results of this question are two-fold, and provide for a stark differentiation. On one hand, the ADaM cube could be used as a device of *development speculation*, as an indicator of areas most prime for reorganization. The tool would be important in revealing highly accessible locations for investment in housing and business. On the other hand, the ADaM cube may prove invaluable as a *tool of advocacy*, helping to indicate neighborhoods and individuals at the greatest risk of impact from redevelopment. The ADaM cube may evoke financial even ethical quandaries, which must be seriously considered to ensure the tool serves the needs of the greater public.

Above all, it is important to remember the basic architecture of the model in relationship to the expectations placed upon it. The ADaM cube and the programs used in its creation are just a few of many tools needed to examine urban space. This research is one step among many in the continued study of urban spatial theory.

## REFERENCES

- Abbott, C. 2011. *Portland in three centuries: The place and the people*. Corvallis, OR: Oregon State University Press.
- ArcGIS. 2016. *ArcGIS Resources*. Redlands, CA: Environmental Systems Research Institute. Available at <http://resources.arcgis.com/en/help/> (last accessed 5 Feb 2016)
- Besussi, E., N. Chin, M. Batty, and P. Longley. 2010. The structure and form of urban settlements. *Remote sensing and digital image processing*. 10(2): 13-31.
- Borchert, J. 1967. American metropolitan evolution. *American Geographic Society*, 57(3): 301-332.
- Camagni, R., M. Gibelli and P. Rigamonti. 2002. Urban mobility and urban form: The social and environmental costs of different patterns of urban expansion. *Ecological Economics*. 40(2): 199–216.
- Cervero, R. and K. Kockelman. 1997. Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment*. 2(3): 199-219
- Bureau of Development Services, The City of Portland, BDS. 2016. Zoning and land use. Available at: <https://www.portlandoregon.gov/bds/article/411748> (last accessed 3 Jan 2016)
- Bureau of Planning & Sustainability, The City of Portland, BPS. 2016. Available at: <https://www.portlandoregon.gov/bps/article/363163> (last accessed 2 Feb 2016)
- City of Portland Archives. 2016. Portland Archives and Records Center. <http://www.portlandonline.com/auditor/index.cfm?c=51811> (last accessed 25 Jan 2016)
- Conzen, M. 2001. The study of urban form in the United States. *Urban Morphology*. 5(1): 3-14.
- Crane, Randall. 2000. The influence of urban form on travel: An interpretive review. *Journal of Planning Literature*, 15(1): 3-23.
- Cresswell, T. 2013. *Geographic thought: A critical introduction*. West Sussex, UK: Wiley-Blackwell.
- Cresswell, T. 2015. *Place: An introduction*. West Sussex, UK: Wiley-Blackwell.

Dill, J. 2004. *Measuring Network Connectivity for Bicycling and Walking*. Portland, OR: Portland State University, School of Urban Studies and Planning. Available at: <http://reconnectingamerica.org/assets/Uploads/TRB2004-001550.pdf> (last accessed 23 Nov 2015)

Doka G. 2013. The excel 3D scatter plot. Available at: <http://www.doka.ch/Excel3Dscatterplot.htm> (last accessed at Jan 10 2016)

Downtown Development Group LLC. 2016. Ankeny Blocks. Available at: <http://theankenyblocks.com/> (last accessed 26 Feb 2016)

Ewing, R. 1996. *Best development practices: Doing the right thing and making money at the same time*, American Planning Association, Chicago, IL.

Ford, L. 2003. "America's new downtowns." The evolution of the American downtown: *Creating the North American landscape*, p. 51-54. Johns Hopkins University Press.

Fyfield P. 2003. Transportation and land use patterns: Monitoring urban change using aerial photography, Portland, Oregon 1925-1945. Master's Thesis. Department of Geography. Portland State University. Paper 2242.

Gehl, J. 2010. *Cities for people*. Washington, D.C.: Island Press.

Google. 2016. Google street view. Available at: <https://www.google.com/maps/streetview/> (last accessed 1 Mar 2016)

Hanson, S. and G. Giuliano. 2004. *The Geography of urban transportation*. New York, NY: Guilford Press.

Harvey, D. 1975. The Human consequences of urbanization, by B. Berry. *Annals of the Association of American Geographers* 65 (1): 99-103.

Levy, A. 1999. Urban morphology and the problems of the modern urban fabric: Some question for research. *Urban Morphology*, 3(2): 79-85.

Lynch, K. 1960. *The image of the city*. Massachusetts Institute of Technology. Cambridge, MA: MIT Press.

Jacobs, J. 1961. *The death and life of great American cities*. New York, NY: Random House.

Knox, P. and McCarthy, L. 2011. *Urbanization: An introduction to urban geography*. New York, NY: Prentice Hall.

Muller, P. 1995. Transportation and urban form: Stages in the spatial evolution of the American metropolis. In *The geography of urban transportation*, ed S. Hanson, 29, New York, NY: Guilford.

Mumford, L. 1961. *The city in history: Its origins, its transformations, and its prospects*. Boston, MA: Mariner Books.

Oregon Historical Society. 2002. *Wooden beams and railroad ties: The history of Oregon's built environment*. Available at:  
[http://www.ohs.org/education/oregonhistory/narratives/index.cfm?nar\\_ID=D432023F-DB0B-EEB8-2CAAF32F6DFE5978](http://www.ohs.org/education/oregonhistory/narratives/index.cfm?nar_ID=D432023F-DB0B-EEB8-2CAAF32F6DFE5978) (last accessed 02 Dec 2016)

Paez, A., and D. Scott. 2005. Spatial statistics for urban analysis: A review of techniques with examples. *GeoJournal*, 61(1): 53-67.

Portland Bureau of Transportation, PBOT. 2016. Available at:  
<https://www.portlandoregon.gov/transportation/45195?a=167703> (last accessed 3 March 2016)

Portland Plan. 2016. *5b, 20-minute neighborhoods*. Available at:  
<http://www.portlandonline.com/portlandplan/index.cfm?a=288098&c=52256> (last accessed 04 Feb 2016)

Pred, A. 1983. Structuration and Place: On the Becoming of Sense of Place and Structure of Feeling. *Journal for the Theory of Social Behavior*. 13 (1): 45-68.

Price, L., D. Johnson, J. Ashbaugh, S. Dotterrer, C. Abbott, T. Poulsen, R. Lycan. 1987. *Portland's changing landscape*. Portland, OR: Portland State University Geography Department.

Regional Land Information System. 2016. Metro. Available at:  
<http://rlisdiscovery.oregonmetro.gov/?resourceID=6#> (last accessed 17 Feb 2016)

Relph, E. 1976 A sense of place and authentic place-making, *Place and Placelessness*. London: Pion Limited. pp. 63-78.

Rodrigue, J. 2016. *Urban Land Use Models in Urban Land Use and Transportation*. Hofstra University. New York Department of Global Studies and Geography. Available at:  
<http://people.hofstra.edu/geotrans/eng/ch6en/conc6en/ch6c2en.html> (last accessed 11 Mar 2016)

Soja, E. 2000. *Postmetropolis: Critical studies of cities and regions*. Oxford, UK: Basil Blackwell.

Song, Y., and G. Knapp. 2004. Measuring urban form: Is Portland winning the war in urban sprawl? *Journal of the American Planning Association*, 70(2): 210-225.

SPSS Modeler. 2016. *K-means Node*. Armonk, New York: IBM Knowledge Center. [https://www01.ibm.com/support/knowledgecenter/SS3RA7\\_15.0.0/com.ibm.spss.modeler.help/trainkmeansnode\\_general.htm](https://www01.ibm.com/support/knowledgecenter/SS3RA7_15.0.0/com.ibm.spss.modeler.help/trainkmeansnode_general.htm) (last accessed 30 Jan 2016)

Teaching American History Project. 2016. Historic GIS data: Portland's people and places. Available at: [http://www.upa.pdx.edu/IMS/currentprojects/TAHv3/PDX\\_Places\\_GIS.html](http://www.upa.pdx.edu/IMS/currentprojects/TAHv3/PDX_Places_GIS.html) (last accessed 20 Feb 2016)

Tsai, Y. 2005. Quantifying urban form: Compactness versus "sprawl." *Urban Studies*, 42(1): 141-161.



## APPENDIX

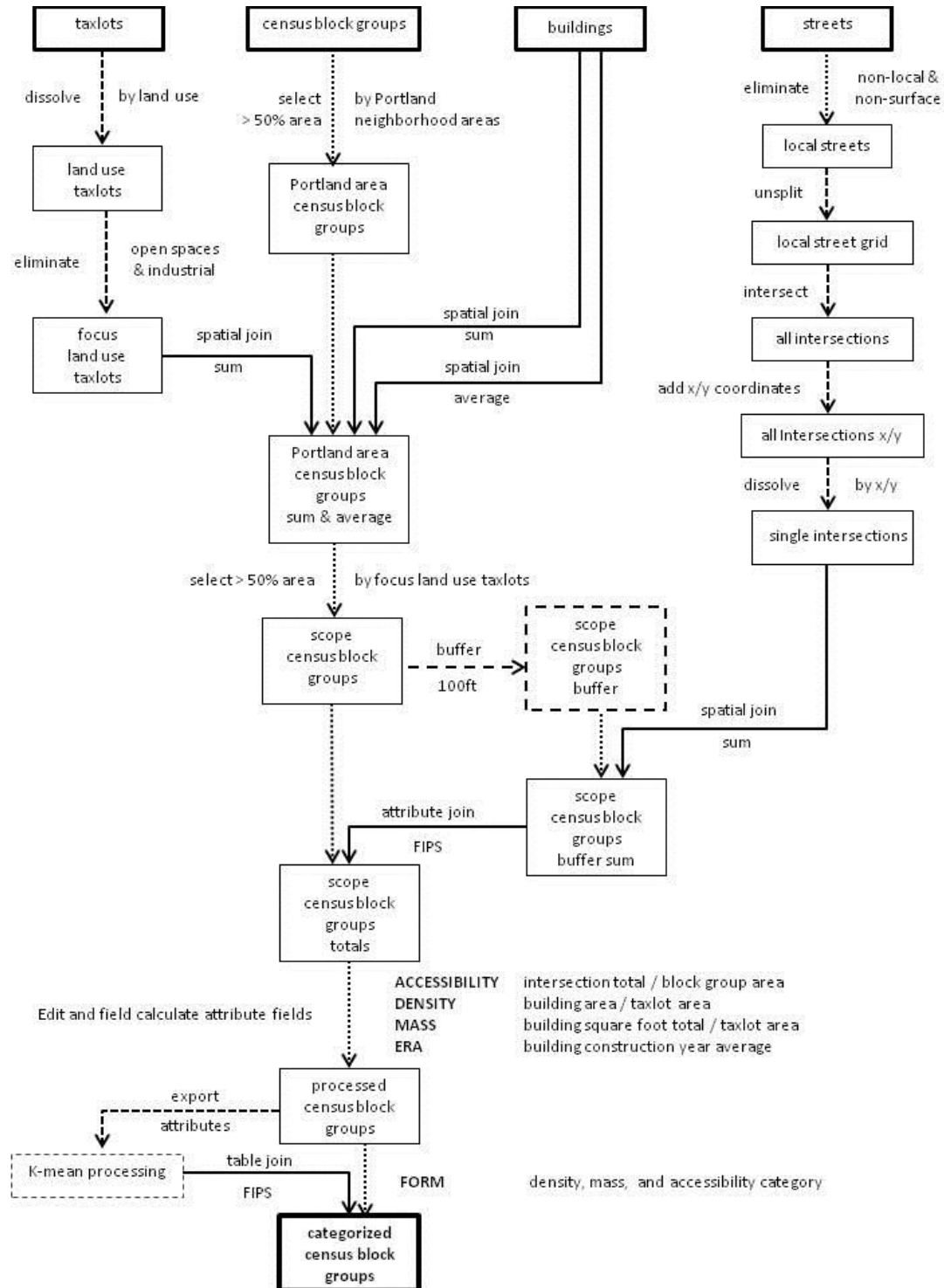


Figure A.1: Data processing workflow

Layer	Field name	Purpose	Statement
Taxlot/ property parcels	PRPCD_DESC	Eliminate areas outside of research scope and geographic extent. Used to omit census block groups with mostly vacant or large properties historically without structures or transportation.	"PRPCD_DESC" NOT IN ('AIRPLANE HANGAR', 'CENTRALLY ASSESSED', 'INDUSTRIAL GENERAL', 'INDUSTRIAL GENERAL USE', 'INDUSTRIAL SPECIAL', 'INDUSTRIAL SPECIAL PURPOSE', 'LUMBER YARD', 'MISC IMPROVEMENTS', 'MISC RECREATION', 'VACANT LAND' , 'WHSE DOCK-HIGH DISTRIBUTION' , 'WHSE GENERAL/LIGHT MFG>15000 SF' , 'WHSE TRUCK TERMINAL' )
Street centerlines	TYPE, and STRUC_TYPE	Eliminate limited access roadways. Used to omit freeways, overpasses, onramps, and tunnels.	"TYPE" NOT IN ( 1110, 1120, 1121, 1122, 1123, 1221 , 1222 , 1223, 1700, 1800, 5201, 9000) AND "STRUC_TYPE" NOT IN (21, 23, 32)

Table A.1: Features attributes and query statements.

Layer	Source	Spatial data	Attributes
Building footprints (vector polygons)	RLIS	Location Dimensions	Construction year Total floor area (all floors)
Taxlot / property parcels (vector polygons)	RLIS	Location Dimensions	Land use (property description)
Neighborhoods (vector polygons)	RLIS	Location Dimensions	
Street centerlines (vector polyline)	RLIS	Location	Roadway type
Intersection nodes (vector point)	RLIS (edited)	Location	
City annexations (vector polygons)	BPS	Location	
Zoning changes (vector polygons)	BDS	Location	Commercial mixed use Residential small lot
Historic roadways (vector polyline)	TAHPDX	Location	
Historic trolley lines (vector polyline)	TAHPDX	Location	
Historic Willamette River (vector polygon)	TAHPDX	Location	
Census block groups (vector polygons)	RLIS	Location Dimensions	FIPS code

Table A.2: Necessary features and visual layers. (Bureau of Development Services-BDS 2016, Bureau of Planning and Sustainability-BPS 2016, Regional Land Information System-RLIS 2016, Teaching American History Project-TAHPDX 2016)